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A New Brake Lining Marking System for Truck Tractors

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Foreword

The research described in this report was sponsored by the U.S. Department of Transportation, National Highway Traffic Safety Administration, C.J. Britell, program manager. The objectives of the work were to research current methods for testing truck tractor brake lining performance, to identify which of them would be suitable for grading aftermarket products, to identify needs for improved lining test methods, and to propose a marking code and methodology for identifying replacement lining products in a way that would enable small and large truck fleets to select replacement linings for their vehicles. The effort was not intended to be limited only to tractor-trailer rigs, but also to straight trucks, buses, and heavy vocational vehicles. Most of this effort concerned S-cam-type drum brakes, but the ability to handle other designs was considered as well. Oak Ridge National Laboratory (ORNL) was selected to perform this work because of its experience in brake materials characterization and because it represented an objective third-party, operating without potential commercial bias.

A variety of industry, trade organization, and government sources participated in this effort. In particular, the author would like to thank the following individuals for their generous advice, courtesy, and technical assistance during the course of this work:

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In addition to the above, Dr. Ingve Naerheim, Tribo Materials Technology, LLC, who has many years of experience at Rockwell International in brake materials research, was employed as a subcontractor to assist ORNL. His key contribution to these findings has been included in a separate appendix.

The problems that prompted this work have existed for decades, and in frank honesty, it was not expected that the current effort would fully resolve them. Yet, we feel that we have made significant progress in crystallizing the issues and have identified possible near-term and longer-term paths to resolving them. The near-term marking code is felt to be a realistic, pragmatic approach. It would require no new testing methods and could be constructed based on existing standards. No new technology would be required. On the other hand, the authors believe that the long-term proposal is technically better and could handle more types of brakes and vocations. It would, however, require a significant investment in test method development and would require a cultural change on the part of the brake producers and users. Consumer education and willingness to change are seen to be important elements of the prescription for success. Suggested follow-up activities are discussed.

Peter J. Blau
September 30, 2003

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Acronyms and Terminology

ABS	Antilock braking system, a system in which an on-board computer adjusts brake pressure to avoid dangerous uneven braking, fishtailing, jack-knifing, or rollovers.
APTA	American Public Transportation Association, an organization that advocates for issues affecting organizations that design systems and provide public transportation, including bus, commuter rail, and rapid transit.
ASTM	American Society for Testing and Materials, an international society that develops voluntary consensus standards for testing materials and handling information related to materials. Each year the group publishes more than 12,000 new, revised, or existing standards from 130 technical committees.
ATA	American Trucking Associations, Inc., an organization of trucking companies and their suppliers headquartered in Alexandria, Virginia, that provides information and promotes legislation that benefits its membership.
BEEP	Brake Effectiveness Evaluation Procedure, a voluntary self-certification program developed by the Brake Manufacturers Council that identifies automotive replacement linings with a special seal.
BMC	Brake Manufacturers Council, established in 1973, functions to provide communication and information regarding local, State, and national issues and regulations that affect brakes and braking systems. Like the Heavy-Duty Brake Manufacturers Council, it operates within the Motor and Equipment Manufacturers Association.
Chase Test	A widely used test method for measuring the friction and wear of brake lining materials. It uses a small pad specimen sliding, under a dead weight load, against the inside surface of a cast iron cylinder designed to simulate a brake drum.
D³EA®	Dual Dynamometer Differential Effectiveness Analysis, a dual-ended (one front brake and one rear brake) dynamometer procedure that has been shown to correlate with FMVSS 105 or 135. Both disc and drum brake hardware can be evaluated. D ³ EA® uses vehicle-specific hardware. A software package is employed to assess the compliance of a front and rear combination of friction materials with the requirements of FMVSS 105 or 135, as applicable.
DOT	The United States Department of Transportation.
ECBS	Electronically controlled braking systems, an advanced, integrated braking system concept that eventually may replace conventional air brake piping with electronic signals to the wheel brake actuators. Computer-based, it offers more rapid control of braking response (shorter stopping distance) and the potential to save weight by eliminating the air distribution system.

FAST (Test)	Friction Assessment and Screening Test, a procedure developed to screen brake lining formulations and to provide quality assurance. It uses a 1"x 1" square pad held against a spinning disk for a set period of time. Measurements of torque, weight loss, and dimensional change provide friction and wear assessments.
FMVSS	Federal Motor Vehicle Safety Standard, a Federal regulation that specifies a method or criterion for assessing the safety-related performance of a vehicle or component part of a vehicle.
GAWR	The maximum permissible gross (loaded) axle weight rating for a given vehicle axle. Due to design and loading configurations, different axles on the same vehicle may have different GAWRs.
HDBMC	Heavy-Duty Brake Manufacturers Council, a trade organization mainly composed of brake lining and braking system manufacturers that operates within the Motor and Equipment Manufacturers Association.
IBT	Initial braking temperature, the temperature of the drum or lining at the time that braking starts.
ISO	International Organization for Standardization, a group that develops and coordinates standards (over 13,000 annually) for business and industry. It operates through a number of technical committees, subcommittees, and working groups.
MEMA	Motor and Equipment Manufacturers Association, an organization established in 1904 to represent motor vehicle and component manufacturers. It is headquartered in Research Triangle Park, North Carolina.
Metric	In material testing, a metric is a quantity that can be used to assign a numerical value to a measure of quality or goodness. Selecting one or two metrics from the many possibilities available to measure brake performance is a major technical challenge.
NHTSA	National Highway Traffic Safety Administration, an agency of the U.S. Department of Transportation that conducts research and issues FMVSSs to improve highway safety.
OEM	Original equipment manufacturer, a company that manufactures powered or unpowered vehicles (trailers), or a component supplier to a vehicle manufacturer.
ORNL	Oak Ridge National Laboratory, located in east Tennessee, is a national research and development organization within the U.S. Department of Energy. It is currently managed under contract to UT-Battelle LLC.
PRI	Performance Review Institute, an organization that is affiliated with the Society of Automotive Engineers. The PRI has a heavy-duty brake lining qualification program that involves evaluating test results on brake lining products and publishing lists of lining performance data.

RBS	Regenerative braking systems use motor-generators, hydraulic pressure accumulators, or other means to store energy from the drive train during braking. This method reduces the demand on friction brakes, offering a potential to downsize the brake hardware and decrease demands on the linings.
RP 628	A recommended practice, developed by the Technology and Maintenance Council, related to the characterization of brake lining torques for products intended for gross vehicle axle weights over 17,000 lbs.
S-Cam Brake	A type of drum brake that is actuated by the rotation of an S-shaped part (cam) that causes the shoes to be forced against the inside of a circular brake drum that is, in turn, connected to the wheels of the vehicle. It is typical of the majority of brakes used on (Class 8) heavy tractors and trailers in the United States.
SAE	Society of Automotive Engineers, a trade organization specializing in the engineering issues of automobiles, trucks, and other vehicles. It is involved with all aspects of design, performance, testing, and regulation.
Spectrum Test	A spectrum test, in the current context, is one in which a carefully selected series of pressures and speeds are applied to a brake lining to simulate conditions that the brakes might experience if they were to be used in specific kinds of trucks or buses.
TMC	Technology and Maintenance Council, an organization of trucking companies and suppliers concerned with all aspects of the operation of commercial vehicles, their maintenance, and technology and regulations that may affect the future of the trucking industry. The TMC develops and publishes recommended practices for a variety of vehicle operations.
Tribology	The field of technology that includes friction, lubrication, and wear, and encompasses both the fundamental science of surfaces and the applied engineering aspects of bearings, gears, brakes, oil formulation, and other friction and wear-related subjects.
VMRS	Vehicle Maintenance Reporting Standards, a structured coding system begun in 1970 and maintained by the American Trucking Associations. It provides standard identifying codes for such things as vocational vehicle uses, types of maintenance problems, commercial suppliers, and many types of truck parts. Recent enhancements enable linking supplier names to Dun and Bradstreet corporate identification numbers.
Vocational	A term that describes vehicles that have specific purposes, such as a garbage hauler, an armored vehicle, a dump truck, a fuel truck, a bus, a cargo van, a refrigerated food delivery truck, etc.

1.0 Executive Summary

Objective, Performer, and Sponsor. The objective of this project was to develop a new, standardized marking code for truck tractor foundation brake linings. This code is intended to meet a currently unfulfilled need to help operators of both large and small truck fleets select replacement brake linings. This marking code could also be used for tracking original equipment linings since those selecting aftermarket products will need metrics with which to match. This project was conducted by staff members of Oak Ridge National Laboratory under sponsorship of the U.S. Department of Transportation, National Highway Traffic Safety Administration, with C.J. Britell as project manager.

Simply stated, two of the main challenges for this project were:

- (1) To select what specific information should be marked on brake linings so that replacement linings will provide the same driver feel and vehicle performance as the worn-out linings they are intended to replace, and
- (2) to suggest a way to mark the lining code on the product to enable it to be readable after months or even years of exposure to dirty road conditions.

An additional related objective is to broaden the applicability of the marking code to cover a range of vehicles and brake designs that are used on trucks and buses of many types and to enable the code to reflect future changes in testing methods or brake designs.

Background. Both large fleet operators with thousands of trucks and small, two- to five-truck, family hauling businesses have long demanded a better and more reliable way to select aftermarket linings that will match the performance of original equipment linings (that is, provide safe and consistent braking over the life of the lining). They are also concerned with the issue of cost versus performance and service life. Currently, replacement lining selection is primarily based on the recommendations of lining salespeople, the personal experience of the buyer, and the sales price. Developing a marking code and having it accepted by industry and consumers is far from simple. The complexity of the underlying engineering and economic challenges has resulted in efforts that span more than three decades.

A brake lining, or any engineering material for that matter, has both *properties* and *characteristics*. Properties are things like the melting point, density, elastic constants, and thermal conductivity. Properties are material constants, whose values are independent of the method of measurement. Characteristics, on the other hand, are observed or measured responses when materials are placed into a specific piece of hardware and operated in a certain environment. Therefore, friction, torque, and wear behavior of brake linings are material characteristics, not basic properties. Consequently, any tests used to measure characteristics reflect the behavior of both the materials and the test hardware. Material characteristics obtained from any lining test machine must therefore be correlated with how the material behaves when installed in a truck. Making that correlation requires careful research and development.

The technical challenge of selecting the correct test on which to base a lining marking code is formidable. Considerable investments of time and effort have been made to develop useful brake tests. These have involved the work of private companies, as well as trade and professional groups like the Society of Automotive Engineers Brake Linings Committee, the Heavy-Duty Brake Manufacturers Council, domestic brake lining manufacturers, testing laboratories, and the Technology and Maintenance Council of the American Trucking Associations.

Uncertainties in Testing. Most current brake lining material tests performed in the trucking industry involve using an inertia dynamometer. Inertia dynamometers are large testing machines, some of them over ten feet long, that use massive, spinning weights attached to a shaft that has brake hardware mounted

on the end. Large spinning weights generate the horsepower needed to simulate the energy of a truck axle under load. After these massive weights are spun up to a desired speed, equivalent to some number of miles per hour, the brakes are applied to slow or stop the shaft from turning. This results in the generation of high forces (torque) and high temperatures that are measured and recorded by sensors connected to a computer. Standardized inertia dynamometer tests that industry engineers have designed usually involve hundreds of stops under various speeds, braking pressures, and lining temperatures. Interpretation of the test results is complicated and requires considerable training and expertise. Concerned with the meaningfulness of such tests, NHTSA funded several projects that indicated problems with the repeatability and significance of inertia dynamometer-based test methods. Sometimes running the same expensive test again and again produced different results from the same lining material. The key question then becomes: How many times does one have to test each type of lining to measure its true behavior? Selecting which test results to include in the lining marking and how many times to run the test to get useful data is therefore both a cost issue and a technical issue. Formidable challenges for developing and implementing the marking code include:

- **How to replace “like with like.”** The source and manufacturer of the lining needs to be identified for those who seek to replace “like with like.” This challenge turns out not to be trivial because lining products and their designations may change, either based on new product formulations or business decisions. In order to match original linings, the original linings would have to be tracked using the same code as the replacement linings.
- **Which characteristics are important?** Which, and how many, lining characteristics are needed to provide a workable means to distinguish one lining from another remains unclear. Should they involve characteristics like “fade” that are important in long descents or frequent start-stop braking? Should they involve hot- and cold-weather braking performance? Should they include a measurement of wear life, an important cost-versus-performance factor for those who buy replacement linings? These issues are discussed in light of which characteristics are and are not measured by current tests.
- **Legacy of test development.** Current industry lining test procedures have improved over the years but fall well short of perfection. To some degree, all suffer from the need to use complex protocols on specialized, expensive equipment. There is a high cost per data point in many cases, and therefore, few repeated tests can be run to establish statistical confidence. The basic properties of the friction material can be hidden within artifacts of the test hardware, automated data recording, and operator adjustments. Some tests do not simulate the truck-braking environment well enough to provide relevant data, or they do not replicate vocational uses (like buses, trash trucks, etc.). Test-to-test data scatter is not small enough to distinguish one lining product from another. Determining which test data would be included in a lining marking code is far from simple.
- **Test data collection and accessibility.** The questions of certifying testing facilities to qualify linings and deciding where the data is to be kept (to backup the lining marking codes) were considered. The use of private-sector, nonprofit organizations to maintain lining data is the preferred course, as long as data integrity, public accessibility, and freedom from bias are assured.
- **Rulemaking versus private-sector controls.** Any lining rating procedure, especially one that requires Federal rulemaking, must address safety to meet the NHTSA mission. Ideally, the brake industry will find a means to police itself without the need for government regulation or rulemaking. NHTSA has the authority to regulate aftermarket

products, as well as new products, but enforcement of aftermarket standards is more difficult.

- **Marking method.** Brake materials inevitably wear away under the harsh environment of road use, and any markings on the side of a lining are likely to be obliterated during use. This makes it difficult to see residual markings on the old lining in order to select a replacement. How and where to mark the lining is a concern. Sophisticated methods for marking might be developed, but their costs may exceed their benefits.

Lack of Consensus. There is strong advocacy for this project among fleet owners and operators, but there is also a diversity of opinion as to what form such a rating code should take. For years, truckers and trucking organizations have been demanding relief from this problem, but the suppliers of lining products and original equipment manufacturers were not overly enthusiastic about developing a new lining rating and marking system. They were especially concerned about the costs associated with implementing any new testing requirements. The issue of wear was particularly contentious. Suppliers strongly object to having a wear rating at all, saying that no single wear test relates to the wide range of ways in which their lining products are used once they are put into service. Suppliers routinely use their own proprietary wear tests to evaluate lining formulations but almost never publish those results.

A Simplified Wear Test. Recognizing that the development of a simple lining material wear test might help reduce the cost of expensive dynamometer procedures, ORNL has designed and built a prototype lining wear test apparatus that uses full-sized S-cam-type shoes. A cast iron puck spins against the surface of the lining, and that wears a divot into the surface. Initial results from this simple, quick, and inexpensive procedure remain to be correlated with field experience. With additional development, that work could lead to a new American Society for Testing and Materials test method.

Near-Term and Long-Term Lining Codes. Two versions of a brake lining marking code are described. Both of them use the same arrangement of letters and numbers, but one was intended as a near-term fix and is based on the use of current test methods. The second is believed to be a better, but more rigorous, solution. It is based on the development of new test methods that isolate the lining material characteristics and differentiate between lining performance for different vehicle types and uses. The format for both near-term and long-term versions is flexible enough to include both drum brakes and disc brakes in the future.

The proposed marking code contains six alphanumeric segments to specify (a) brake design, (b) gross axle weight rating, (c) service code (optional), (d) manufacturer code (using Vehicle Maintenance Reporting Standards to identify companies), (e) manufacturer's product designation, and (f) selected results from the inertia dynamometer test portion of the Federal Motor Vehicle Safety Standard 121. Item (c) is an optional service code that indicates particular uses for which the manufacturer especially recommends this lining (frequent starts and stops, high temperature, off-road, etc.). An example follows for a drum brake with a 23,000 lb. GAWR, intended for highway or regional delivery service, made by Jones Brakes, having the product designation AB20, and that passed FMVSS 121 dynamometer tests at 20 and 80 psi air line pressures with torques that fell into range 2 for low pressure and range 3 for higher pressure: **M23-HR-JONES-AB20-P23**. See Section 5.2 for additional details on this marking code.

The longer-term solution to a lining marking system is similar to the near-term system, but uses different test methods for segment (f). Segment (f) of the more advanced code is based on the recognition that current dynamometer-based tests have certain technical problems that contribute to test-to-test variability. The longer-term solution therefore replaces part (f) with data from a more vehicle usage-specific test method, as found in Appendix C of this report. That new qualification test would involve a robust, laboratory-scale, computer-controlled machine that is programmed to simulate standardized braking

service profiles; for example, “long-haul,” “city bus,” “delivery truck,” “trash truck,” etc. New research would be needed to establish operating profiles from vehicle data, develop the hardware and software needed to control the test, and verify that the results are relevant. Data from these spectrum tests would include not only friction coefficients but a wear metric as well. The test results indicated in part (f) of the new code would therefore correspond directly to the intended service code, as indicated in part (c).

One Size Will Not Fit All. Unfortunately and inevitably, the proposed marking code would not satisfy everyone involved in producing or using truck brake linings. Resistance to implementing the proposals in this plan is expected from those who have a significant investment in the current system of supplying, testing, and recommending lining products. In developing this report, compromises were required in the interest of practicality, timeliness, and technical viability. The primary customers for the results of this project were first and foremost the owners, operators, and drivers of the Nation’s trucks; but to be viable, suppliers must embrace it as well. In the end, however, it is the salespeople who interface directly with fleets and drivers who are likely to remain influential in replacement lining selection.

Impacts of Future Brake Technology. Future braking systems will increasingly be automated. Variations in the lining characteristics between one wheel end and another, one axle and another can be, in principle, compensated for by computerized systems. Theoretically, as long as they have adequate wear life, replacement lining materials with adequate frictional characteristics could be allowed to vary more in torque response, with the expectation that the on-board computer system will maintain the proper balance of braking forces and feel to the driver. However, in the near-term (at least 10 years), the characteristics of the lining materials will still need to be considered and selected carefully by the fleets and truck operators. The current marking system is intended to meet that need.

Possible Future Activities. Based on current findings, eight possible future activities are identified and discussed. Five pertain to the near-term code and the last three to the longer-term solution. Some of these activities could be initiated using the remaining project funds (for example, items 2, 4, and 6). Others would require additional investments in funding. Potential follow-up activities and levels of effort in person-years (PY) are indicated in brackets []. Working partnerships and commitments on the part of the trucking industry and its suppliers would be key in the implementation of these future research activities. Therefore, the time needed to implement these activities would depend to a degree on the level of participation of industry partners.

1) ***Initiate a Tracking Program for Brake Linings Supplied with New Trucks.*** Truck manufacturers could be asked to provide information, axle-by-axle, on the lining types they supplied with the original vehicle. This information could be carried on the vehicle; for example, on a door jamb sticker or a code in the electronics control unit. Information would contain the proposed lining code. The method for marking the code on the vehicle and the linings themselves needs to be determined.

[1.1 Determine how to implement a practical method for tracking the lining type provided on new trucks and trailers. 1 PY effort for 2 years.]

[1.2 Investigate practical methods to physically mark brake linings so that the code is still readable when a replacement is required. 1 PY effort for 1 year.]

2) ***Review Dynamometer Data.*** The near-term version of the marking code uses torque data obtained by the FMVSS 121 dynamometer test procedure under two apply pressures (20 psi and 80 psi). This data would have to be obtained for a variety of current lining products to determine how many different torque levels (1, 2, 3, 4, etc.) are technically justified to be used for code segment (f).

- [2.1 Contact sources of FMVSS 121 lining data to obtain 20 psi and 80 psi torque data for a variety of linings. Analyze the range and distribution of this data to help select the number of levels into which the data is divided in marking code segment (f). ½ PY effort for 1 year.]
- [2.2 Conduct a more extensive evaluation of existing FMVSS 121 data to determine how the data could be clearly represented and displayed in a more comprehensive public database on lining performance. Provide the information to the developer of the educational software package (see 3.1). 1 PY effort for 1 year.]

3) **Educate Those With a Need to Know.** Implement a trucking industry education program about the new code system and the lining data that supports it. Methods include (a) presentations to industry groups, (b) trade magazine articles, (c) free pamphlets for distribution to dealers and truck stops, and (d) Internet Web sites. The online educational effort could be funded privately by private industry, DOT, or both. On the basis of preliminary discussions, this educational Web site could be hosted by the TMC.

- [3.1 Develop educational software for the new lining code system and implement it in hard copy and via the Internet. ½ PY effort for 6 months, following acceptance of the lining code.]
- [3.2 Continuing education on the lining code and how to use it can be done through short courses offered by trade organizations.]

4) **Identify a Database Custodian.** The custodian of the test data for specific linings may be a trucking industry organization like the TMC. It makes sense to have both the lining data and the educational material linked through the same Web site.

5) **Provide a Web site and Data Gateway.** The TMC could be approached as the prime candidate to host and maintain the Web site that educates users on the new lining marking system and provides links to a lining test database that supports marking code segment (f). Ideally, the supporting database will be searchable online, based on any of the individual code segments or a combination of segments in the marking code.

- [5.1 Set up a Web site and populate the supporting database with lining test data from one or more validated sources of FMVSS 121 data. 2 PY effort for 2 years.]

6) **Continue to Develop a Cost-Effective Lining Material Wear Test.** Work could continue on developing the relatively simple lining wear test prototyped at ORNL. This would involve obtaining additional data on several linings and investigating the degree to which laboratory wear test results agree with fleet experience with the same kind of lining. If successful, the test could be standardized either under ASTM (Committee G-2 on Wear and Erosion) or SAE (Brake Linings Committee), and additional units of the machine could be commercially produced.

- [6.1 Establish the final testing protocol, then obtain and wear-test lining materials whose performance covers a range of durability. 1.5 PY effort distributed over 2 years.]
- [6.2 If results warrant, prepare an ASTM Standard Practice describing the lining wear test and work through Committee G-2 on Wear and Erosion to standardize it. ½ PY effort distributed over 2 years.]

7) **Develop Operating Use Spectra.** To enable the development of vocation-related test protocols, a longer-term program could be initiated to collect data on the operating conditions of brakes on selected vehicles. It is suggested that this work would begin with three types of vehicles: (1) line-haul tractor-trailers, (2) school buses, and (3) straight trucks for local delivery.

8) [7.1 Develop operating spectra for three representative vehicles through instrumenting test vehicles or accessing existing data. 2 PY effort distributed over 2 years.]

8) *Development of a Spectrum Test Method.* A laboratory test system on which the operating profiles of various vehicles can be programmed and applied could be selected and developed. This could be based on an existing test or a new system. Cost, accessibility to testing facilities, and potential for standardization would be prime considerations. In-kind industry contributions (access to facilities and technical advice) would be critical to support this effort. If successful, the data from this test would replace that used for the near-term rating code, segment (f).

[8.1 Develop a test machine and conduct spectrum tests to simulate the operating profiles defined by the work following 7.1. 3 PY effort distributed over 3 years.]

2.0 Introduction and Project Objective

The objective of this project was to develop guidelines and possible future activities aimed at establishing a practical rating system for truck tractor brake linings, particularly those used to select aftermarket, replacement linings.

The complexity of the underlying engineering challenge has resulted in a series of research, development, testing, and evaluation efforts that extended over three decades. Strawhorn has recently discussed this problem critically (see **Appendix A**). Reaching a practical solution has been complicated by issues including the selection of the appropriate testing protocols, the scale of testing required (ranging from full-sized vehicles to laboratory apparatus), the repeatability and reproducibility of test methods, and the considerable investments of individuals and groups like the SAE Brake Linings Committee, the SAE Performance Review Institute, the HDBMC, domestic brake lining manufacturers, testing laboratories, and the ATA's TMC. While there is strong advocacy for this project among fleet owners and operators, there are divergent opinions on what form such a rating system should take and how lining ratings should be measured and used.

The ORNL has been studying this issue from the viewpoint of an objective third party. The first step in that process involved gathering information from a variety of sources, including industry groups. The ATA's 2003 North American Truck Fleet Directory-Interactive lists 70,795 commercial truck fleets, so the task of acquiring information and opinions that represented the broadest spectrum of interested parties was daunting. To a certain extent, news articles about the project in trucking magazines elicited comments, but most of the background was developed through participation in conferences, attending meetings with industry groups, and private discussions with brake experts. During the latter stages of the work and during the summary phase, ORNL obtained the services of Dr. Yngve Naerheim of Tribo Materials Technology and formerly of Rockwell International Science Center.

Early in the project, it was decided to start with a "strawman" (a design created with the specific intent of discarding it) for a new rating system and then refine it as information and feedback from industry groups was received. The first strawman was presented to the HDBMC in August 2002. This preliminary version included eight material properties and characteristics, but the HDBMC felt that it was too complicated and unworkable. A second strawman was developed in the fall of 2002 and presented at the TMC Meeting in Charlotte, NC (October 2002), and at the SAE Truck and Bus Exposition in Detroit, MI (November 2002). Subsequent discussions resulted in a new, simpler version that was first circulated in March 2003.

Ideally, the new rating system developed in this project would be suitable for truck brakes of various designs, including the popular S-cam drum brake design as well as air brakes and hydraulic disc brakes. However, for technical reasons, disc brake testing practices and regulations seem to be at a more advanced state of development than those for drum-type brakes. Therefore, it seemed prudent to focus on drum brakes for the major portion of this effort.

3.0 Fact-Finding

Fact-finding involved the assimilation of data from a variety of sources, each of which may have had a slightly different perspective on what was needed for an effective brake lining rating system. The data was collected from the following sources:

- ◆ Private discussions with brake engineers, consultants, testing professionals, sales representatives, government regulators, and leaders of professional groups;

- printed literature and Internet information
- meetings with trucking industry groups
- published notices and editorials in trade magazines like *Heavy-Duty Trucking* (October 2002)
- opinion surveys conducted among fleet owners and operators
- feedback from presentations given at society meetings; and
- trial strawmen and position papers circulated for comment.

In the following section, the fact-finding resources will be delineated and the most relevant findings summarized.

In fact, it is difficult to sample the opinions of most fleet owners and operators due to the large number of small firms operating in the United States. A substantial portion of such small firms do not send representatives to major organizational meetings, like those of the TMC and SAE, so the opportunity to solicit their opinions is limited. Even so, a small fraction of those provided with surveys took the time to respond. On the other hand, the sources of information from which this project has drawn conclusions represented some of the most important truck brake industry leaders in the United States, and that provides a measure of credibility to the conclusions. Efforts were made to distinguish the author's viewpoints from those of industry information sources, and there was no intent either to misrepresent or to bias the information in any particular way.

During the course of this project, it became evident that:

- ❑ The needs and expectations differed markedly among the stakeholders in this project (lining makers, OEMs, trade organizations, testing companies, transit authorities, and DOT/NHTSA). Those who sell linings to truckers (face-to-face) have a large influence on what is purchased, especially by the smaller fleet operators.
- ❑ Any new brake lining rating/marketing system would ultimately have to be a compromise and will therefore not meet all the needs and expectations of all the interested parties.
- ❑ Technical problems in testing, like establishing the repeatability of results and reaching an agreement on performance criteria, continue to hinder the ability of the brake engineering community to reach a consensus on which lining metrics to use in a standard marking code.
- ❑ Truck brake test development activities in the United States have focused on S-cam drum brakes and then mostly on the 16.5" x 7" size, leaving a significant need to address ratings for other sizes (as for steer axles) and other designs (air brakes and hydraulic disc brakes). European activities in performance testing may provide models for addressing the latter.
- ❑ Like many other industries, the truck brake industry resists change unless government mandates or competition forces such changes to occur. Technology education is also needed to enable more informed choices of lining products, and there is a possibility of linking the new rating system with user education; for example, with a tutorial Web site on the Internet.
- ❑ Wear and durability ratings were among the most controversial technical issues, and lining manufacturers resisted including these data in any rating system.

The fact-finding process that led to our final conclusions is presented chronologically in the following sections to reflect the evolution of thinking that went on as the project continued.

3.1 *Heavy-Duty Brake Manufacturers Council (HDBMC).*

The purpose of this meeting was to describe the new NHTSA/ORNL project to develop a truck brake friction material rating system to members of the HDBMC, and to solicit comments on the first ORNL “strawman.” This was the “kick-off” industry meeting for the project and focused on issues of concern to friction material manufacturers and suppliers. The meeting, arranged by Jim Lawrence, HDBMC, was held in Alexandria, Virginia, beginning on the afternoon of August 14, 2002, and continuing on the following morning. The following 12 people were in attendance:

Name	Organization
Jim Lawrence	MEMA, HDBMC
Peter Blau	Oak Ridge National
Jim Britell	DOT/NHTSA
Jon Mueller	DOT/NHTSA
Samuel Daniel	DOT/NHTSA
Duane Perrin	DOT/NHTSA
Jim Szudy	Bendix
Don Davidson	Arvin Meritor
Jim Fajerski	Federal Mogul
Randy Petresh	Haldex
Tom Sheikh	Carlisle
Richard Diemer	BrakePro

By the end of the meeting, the following issues had been discussed:

- ☐ The objective of the new rating scheme for brake material should enable users to select replacements that will perform as well as original equipment friction materials using a very simple rating code.
- ☐ It would be best to keep the number of metrics in the rating scheme to only one or two.
- ☐ The ORNL Strawman #1, as presented, was too complex, and it contained more parameters than the user will know how to handle – eliminate material properties like thermal expansion, flexure strength, etc. These kinds of material properties are often required by the OEMs and provided by suppliers, but they are far more than the (aftermarket) user wants to know or can handle.
- ☐ TMC RP 628 is now in fairly widespread use (even if originally intended as a stop-gap measure), but the 40-psi-required pressure is more like an emergency stop condition, and 20 psi would be more realistic for this rating.
- ☐ Nothing short of a dynamometer test would satisfy torque data needs, so bench lab tests for friction of these materials are not likely to be accepted.
- ☐ Wear is not normally a part of the current qualification schemes; however, it is of interest due to its impact on cost. The desirability of including wear in the rating scheme was not unanimous. For example, one manufacturer saw a problem with establishing a standard wear protocol. No

single lining user's operational profile would fit the "standard," so ratings would not be useful for individual needs. On the other hand, it was pointed out that a wear rating could provide a figure of merit similar to the Environmental Protection Agency mileage ratings given to new cars. That number could be a guide even though individual experience might differ.

- ♦ Internally standardized wear test procedures exist at several brake lining manufacturers, but a single test typically requires dynamometer runs lasting a full seven days and could cost \$10,000 or more.
- ♦ While dynamometers might be needed to generate torque data, maybe smaller (lab) scale wear tests would work to develop a suitable relative wear factor.

One problem concerned how a single metric or even two could represent the performance of a lining under a range of conditions. Tire rating codes were mentioned as a model of how lining sellers and buyers might use a simple rating scheme that is relatively easy to understand.

Peter Blau suggested running a survey at the next TMC meeting. That idea was favored by the group as long as it would be short. It was suggested that rather than conduct it at the Thursday brake session in Charlotte, as Blau had proposed, that it be conducted instead at the "town meeting" where there would be more people to respond. Forms could be handed to the "yellow badges" (fleet representatives) when they enter and collected at the door as they leave. Results would be tabulated and ready by Thursday's brake lining special session. As it turned out, however, the surveys were distributed to fleet members of TMC in their registration packets and only about 22 of them were returned.

Jim Lawrence helped compile a list of suggested survey questions to be circulated to HDBMC members for comment prior to sending them to TMC.

It was pointed out by Duane Perrin and Jim Britell that what might be needed is better education of the lining buyers, and that this in itself would be a worthwhile goal. Such a guide might be incorporated in the final report of this project or prepared as a separate document.

Finally, it was decided that copies of the Strawhorn paper (presented at the 2000 SAE Truck & Bus Conference) would be provided to the group since it influenced ATA's advocating the current project.

3.2 Technology and Maintenance Council) Fall Meeting.

The summary of a special one-day workshop in cooperation with the ATA's Technology and Maintenance Council was prepared and published as ORNL Tech Report TM-2003/24. The workshop was held at the Fall 2003 meeting of the TMC in Charlotte, NC. The title of the workshop was *Developing a Useful Friction Material Rating System*. It was organized by a team consisting of Peter Blau (ORNL), Jim Britell (NHTSA), and Jim Lawrence (MEMA), and held under the auspices of TMC Task Force S6 (Chassis), chaired by Joseph Stianche (Sanderson Farms, Inc.).

Six invited speakers during the morning session provided varied perspectives on testing and rating aftermarket automotive and truck brake linings. They were: James R. Clark, chief engineer, Foundation Brakes and Wheel Equipment; Dana Corporation, Spicer Heavy Axle and Brake Division; Charles W. Greening, Jr., president, Greening Test Labs; Tim Duncan, general manager, Link Testing Services; Dennis J. McNichol, president, Dennis National Lease; Jim Fajerski, business manager, OE Sales and Applications Engineering, Federal Mogul Corporation; and Peter J. Blau, ORNL. Copies of these presentations are given in **Appendix B**.

Jim Clark presented an excellent review of the current state of the TMC approach to the aftermarket lining rating situation. He described differences among several brake testing methods. TMC Recommended Practice 628 uses the dynamometer portion of the FMVSS 121 to obtain a torque rating for a 40-psi pressure, but this practice is aimed at 16.5" x 7" S-cam-type drum brakes. It does not address the smaller-sized brakes on steer axles, other wheel sizes, other brake sizes, and other brake designs (air brake or hydraulic disc brakes, for example). Recently, the SAE/Performance Review Institute group made the following suggestions regarding RP 628:

Other brake sizes, types, parameters will be added to:

- Other brakes may not contain "equivalent" actuation systems to that used for RP 628 testing. They may use different cam profiles or lever mechanical advantages (air disc).
- Revise RP 628 to permit other brake configurations, then publish the brand name and full list of parameters, along with the 40-psi torque.
- Allow the market to dictate supplier submissions.

Clark concluded his presentation with the following suggestions:

- A. Require the exact lining formula that was on the new vehicle, as a replacement lining.
- B. Require suppliers to certify the parameters that each aftermarket lining product must meet FMVSS 121 dynamometer test requirements (axle load, tire size, actuation system) and publish torque output.
- C. Develop a large sample lining test that accurately identifies friction level under FMVSS 121-type conditions, identify acceptable ranges, and require all suppliers to test and report findings for each lining.

Note: For B & C, establish a monitoring system for compliance.

Interestingly, one fleet operator commented that he did not like the original linings received on his new trucks and relined them to suit his own service requirements.

Afternoon break-out sessions addressed nine questions concerning such issues as: "Should the Federal government regulate aftermarket lining quality?"; "How many operators use RP 628, and what's good or bad about it?"; and "Would there be any value to you of a vocation-specific rating system?" The opinions of each discussion group, consisting of seven to nine participants, were reported and consolidated in summary findings on each question. Some questions produced a greater degree of agreement than others. In general, the industry seems eager for more information that would allow those who are responsible for maintaining truck brakes to make better, more informed choices on aftermarket linings.

A fleet operator survey was also conducted during the TMC meeting. Twenty-two responses, spanning fleets from 12 to 170,000 vehicles, are summarized in a report.* The vast majority of fleets do their own brake maintenance, relying primarily on experience and lining manufactures to select aftermarket linings. At least half of the responders were familiar to some extent with TMC Recommended Practice 628 on brake linings, but most do not use it as the sole criterion to select linings. As Clark mentioned earlier, significant shortfalls in the applicability of TMC RP 628 to certain types of brake systems were noted.

[*See "Report on the Truck Brake Lining Workshop and Fleet Operators' Survey," P. J. Blau, Oak Ridge National Laboratory, Report ORNL/TM-2003/24, December 2002, 11 pp. Available through NTIS, Springfield, VA.]

3.3 SAE Truck and Bus Exposition.

The ORNL presented an overview of the current project and participated in a panel discussion on “Government-Industry Brake Research Programs” at the SAE Truck and Bus Exposition in Detroit, Michigan, in November 2002. There was an opportunity to receive feedback from both OEMs and fleet operators. There was a particularly strong interest by the New York City Transit Authority in developing a better way to select bus brake replacement linings. Issues involving accidents and passenger litigation are involved. Displays at the SAE commercial exhibit showed some new brake technology, particularly emphasizing electronic condition monitoring and control systems. However, in the end, it is the material interaction that creates the friction to stop the truck.

3.4 TMC Summer Meeting.

The objective and progress of this project was presented during the RP628 update session in Phoenix, Arizona, in June 2003. In private communications just before the meeting, and while soliciting comments on the most recent strawman, it was learned that a proposal for a grading method that included using inertia dynamometer measured torque values for 20 psi, 40 psi (the established TMC RP 628 value), and 80 psi was being considered by a working group within the Bus Standards Brake Working Group of the American Public Transportation Association.* The 20-psi value was felt to apply more to normal truck braking pressures, and 80-psi torque would represent more emergency stopping conditions. The 40-psi value was retained as a compromise value that is used in the TMC RP 628 procedure. It should be noted that the 20-psi value can be influenced by the spring rate on the brake chamber (return spring) that can require 6 to 8 psi alone to activate.

In Phoenix, a private meeting was held to discuss where ORNL stood in relationship to the linings project at that time and to bring up to date Dr. Yngve Naerheim, whose company, TMT LLC, had recently been subcontracted to assist in the project. The meeting was attended by Vic Suski, senior automotive engineer, ATA; Marty Fletcher, director of technology and training, U.S. Xpress Enterprises, Inc.; and Duke Drinkard, chairman of the TMC Tomorrow’s Truck Committee, of Southeastern Freightlines. Suski reviewed the history of ATA’s interest in having a useful lining marking, and Drinkard emphasized the needs of the fleets and was critical of a lack of progress on solving the persistent problem of aftermarket lining selection based on standardized criteria for performance. Suski also emphasized the importance of reducing the variability in lining test methods and the uncertainties in the resulting data.

3.5 International Activities on Brake Lining Testing.

The International Organization for Standardization has an active series of committees, subcommittees, and working groups (WGs) associated with brakes. It was hoped that models might be available to enable the selection of suitable U.S. aftermarket lining designations and test methods, but much of the European and Asian focus has been on air disc brakes since they represent a more significant fraction of truck use in those communities. Roy Link, of Link Engineering, Plymouth, Michigan, is a participant in ISO brake-testing activities and provided information on the organizational structure (Fig. 1 represents a distillation of those activities). Sub-working group (SWG) 3 has an interest in lining properties like compressibility, thermal transmission, swell and growth, density, porosity, shear strength, and shim peeling, but the SWG that most directly relates to the current project issues seems to be in WG2 on brake linings, designated as SWG 4 on Friction and Wear.

[*Ref.: “Recommended Practice for Transit Bus Foundation Brake Replacement Brake Lining Classification.” Draft of APTA BT-RP-002-03]

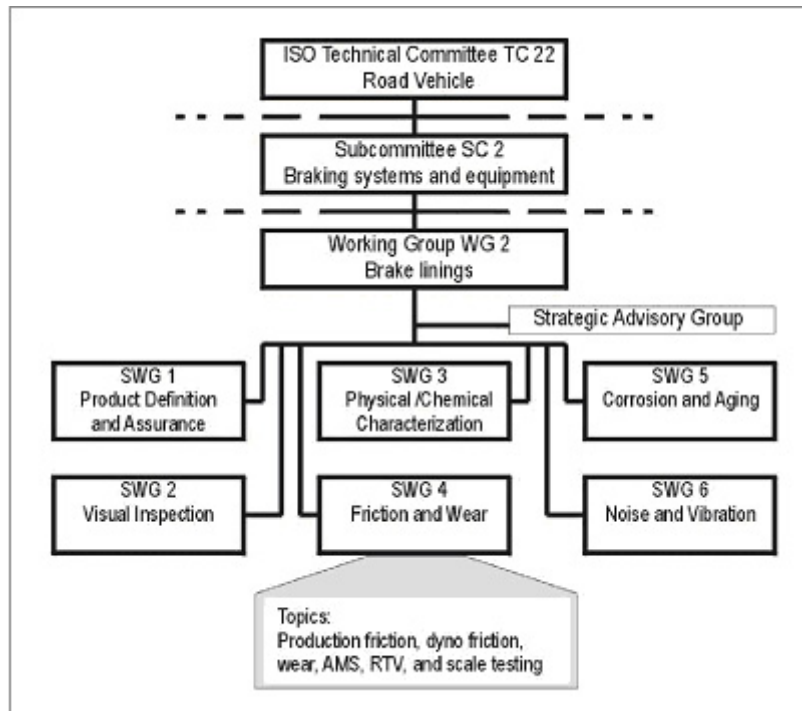


Figure 1. ISO Technical Committee (TC) 22 and related brake activities.

4.0 Technical Issues and Lining Rating System Concepts

During the course of this project, it became increasingly apparent that the complex technical issues associated with lining testing were at odds with the desire of the trucking community for simplicity and ease of lining selection. Engineers argued about things like the variability of test data, how data was sampled, the differences in requirements by OEMs and the aftermarket, the operational definition of “fade,” and the pitfalls of attempting to define or certify a lining wear life. Fleet operators wanted a better way to match the feel and performance of the previous set of brake blocks. They wanted a number, “any number,” that could do the job. To clarify the nature of the problem with picking one or two numbers to qualify a lining, it is first necessary to clearly distinguish between material properties and characteristics.

The Important Difference Between Material Properties and Characteristics

A brake lining, or any engineering material for that matter, has both properties and characteristics. Properties are things like the melting point, density, elastic constants, and thermal conductivity. Property values are material constants, and they should be independent of the method of measurement. Characteristics, on the other hand, are observed or measured responses when materials are placed into a specific piece of hardware and operated in a certain environment. Therefore, friction, torque, and wear behavior of brake linings are material characteristics, not basic properties. Consequently, any tests used to measure characteristics reflect the behavior of both the materials and the test hardware. Material characteristics obtained from any lining test machine must therefore be correlated with how the material behaves when installed in a truck. Making that correlation requires careful research and development.

Braking: From Atoms to ABS. The concept of complex systems, as related to performance measurement of brake lining characteristics, can be illustrated by first considering the formulation of linings. A typical brake lining consists of more than 15 chemical compounds that are blended and processed to produce a

complex composite material. Linings contain such things as metallic particles or metal sponge, mineral chips, rock wool, mineral fibers, carbon (as graphite or in some other form), solid lubricants, ceramic abrasives, and fillers, all held together by a phenolic polymer binder. The structure of a commercial pad material, as seen in a microscope, is shown in Figure 2. A fuller discussion of the formulation of brake linings may be found in G. Nicholson's book *Facts About Friction*, published in 1995 by Gedoran, Winchester, Virginia, and in *Compositions, Functions, and Testing of Friction Brake Materials and Their Additives*, by P. J. Blau, Oak Ridge National Laboratory, technical report, ORNL/TM-2001/64, available through the National Technical Information Service, Springfield, Virginia.

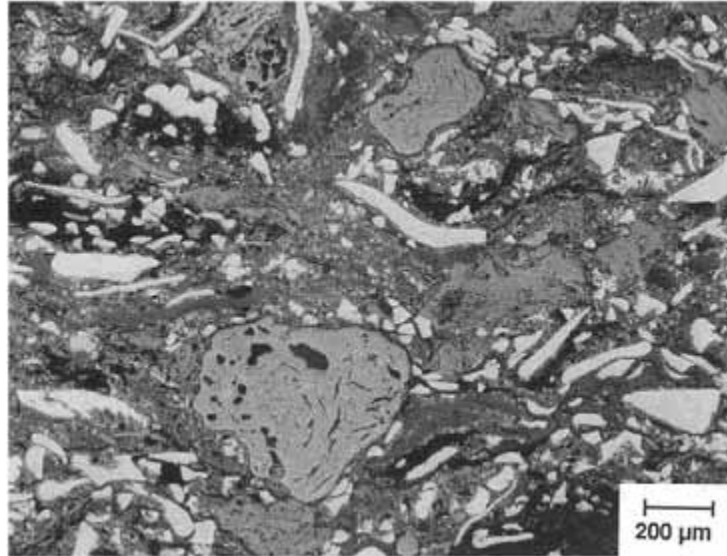


Figure 2. Cross-section of a commercial brake pad material showing a complex combination of additives.

Mixing the Batter. Every ingredient that goes into a lining has its own basic properties, but when blended together, all the ingredients form a completely new composite material with its own set of properties. The process of formulating a lining therefore produces material with new properties and characteristics, but not in a simple and predictable way. Tests like the Gogan hardness (compressibility) test and others have been devised for linings, but these still measure material properties and not the characteristics we need to know about the composite when it gets fabricated in the shape of a brake lining, mounted on the shoe table, and installed on a truck. Therein lies much of the problem in selecting a lining test: at what level of fabrication (from formulation to installation on a truck) will a lining test provide the most meaningful metrics for quality? Table 1 summarizes the implications of this question.

Curing in Service. Measuring a lining material's performance characteristics is further complicated because the lining material completes its curing process only after it has been used for a period of time. In other words, at the time that a new lining is installed in the vehicle, it is only partially processed. Temperatures and pressures on the materials during service continue the curing process, and a brake lining eventually sets into its long-term condition. Therefore, any test performed on a new lining product provides information on the materials in their incompletely cured condition.

Effects of Wear. Brakes deteriorate with wear and tear, altering their characteristics. For example, as wear changes the lining's shape, the pressure of the surface sliding against the drum changes. Corrosion products

may affect the brakes as well. Rusted steel behind the linings can cause them to expand, creating more pressure to be borne by the swollen area and further increasing the wear rate or the tendency to crack. That sequence of events is called *rust-jacking*. Therefore, the state of wear must be added to the list of things that affect the performance characteristics for a lining material

Table 1.
Lining Properties and Characteristics

Level	Types of Tests	Information
1. As-processed formulation	Density, compressibility, flexure strength, hardness, swell, small-coupon friction, and wear tests	Basic material properties of the composite, relative friction and wear characteristics of the material when tested in a certain type of apparatus
2. Assembled brake shoe	Dynamometer friction/wear tests	Characteristics of the material against the counterface material in the environment imposed on it by the dynamometer
3. Installed brake shoe	Vehicle tests	Characteristics of the materials used in the given truck design and when operated in a certain way by the driver. Also affected by tire traction.

The kinetic friction coefficient (commonly indicated by the Greek letter “mu” - μ) is the ratio between the force that opposes sliding between two materials (F_t) and the force (N) that holds them against each other:

$$\mu = \frac{F_t}{N}$$

The friction coefficient is a system characteristic, and therefore, the friction coefficient for the same material combination (“A” sliding on “B”) can vary widely depending on the machine in which those materials are used. Friction coefficients for brake lining materials (against gray cast iron) range between about 0.30 and 0.55. The braking force (F) is directly related to the friction coefficient using the following equation (see a sample calculation in **Appendix A**):

$$F = \mu \left(\frac{2ABSD}{CT} \right)$$

A = air pressure used to apply the brake (psi), B = air brake chamber size (in.²), S = length of the slack adjuster lever arm (in.), D = inside radius of the brake drum (in.), C = in an S-cam brake, the cam radius of brake actuation (in.), and T = rolling radius of the tire (in.). All other factors being equal, if the friction coefficient varies by 20 percent, so does the braking force.

Conservatively estimated, systematic experimental work on friction has been conducted for at least three centuries. Based on extensive testing, the following list of factors are all known to affect friction, and many of these factors are obviously present in brake systems:

Some Factors That Can Affect Friction, Depending on Circumstances

surface finishes of the materials
magnitude of force pressing the materials together
type of motion: oscillating, one way, complex
in oscillating sliding, the length of the stroke
whether there are any wear particles present
whether the machine is vibrating or still
the damping capacity of the mounting hardware
the temperature of the environment
heat flow from the interface to the surroundings
the relative humidity of the environment
the alignment between the sliding partners
aging of the lubricant
filtration of the lubricant
the shape of the slider
the porosity of the surface

composition and properties of the materials
magnitude of the sliding speed
whether the speed is constant or varying
in oscillating sliding, the frequency
whether a lubricant is present
stiffness (elasticity) of the hardware
cleanliness of the sliding interface
frictional heating effects*
presence or corrosive gases or fluids
the regime and properties of the lubricant
the running-in characteristics of the surfaces
time of rest between starting and stopping
lubricant film thickness relative to particle size
orientation of finishing marks or wear grooves
natural frequency of the machine

(* Note: This effect is particularly important for brake fade, an issue discussed in section 5.1.2)

A more detailed discussion of the effects of the foregoing factors on the friction may be found in the book *Friction Science and Technology* (P. J. Blau, 1996, Marcel Dekker, Inc., 399 pages). The immensity of the problem becomes even clearer when it is realized that several factors are changing at the same time in any operating brake (for example, sliding speed decreases, the load [braking pressure] may vary depending on driving conditions, and temperature rises). There is a changing energy balance between the frictional heat generated and the ability of the air cooling and conduction to the surrounding structure to dissipate that heat. In disc brakes, passages, holes, and vents are introduced to control heat flow.

Important Role of Transfer Films. An interesting thing happens when typical brake linings are rubbed on cast iron or another counterface: A thin, often discontinuous layer called a transfer film or glaze forms on both the lining and the counterface surface (drum or rotor disc). A cross section of one such transfer film is shown in Figure 3. Research has shown the friction is controlled by the characteristics of that new layer of material that is formed during rubbing. Certain lining formulations are in fact designed to produce transfer films with specific frictional characteristics. The development of stable transfer films is to some extent dependent on sliding conditions. Therefore, one testing machine may create a different type of transfer film on the braking surface than another, and hence, the frictional characteristics will be different for the two machines even when the same test materials are concerned.

In view of the number of properties present from individual additives, their synergistic effects, and the diversity of factors that affect friction, it is, for all practical purposes, impossible to predict, from basic scientific principles, what the performance characteristics of a brake lining will be ahead of time. Therefore, new lining formulations are subjected to extensive testing, and such testing is a critical element when a new lining is prepared for introduction to the marketplace.

Figure 4 schematically illustrates how materials having certain basic properties react to produce braking characteristics in an S-cam-type drum brake system. It would be wonderful if one could just key the lining properties into a computer program and predict the stopping distance of a certain truck with a certain type of braking system, payload, tire characteristics, road surface, weather conditions and driver, but that heroic feat of engineering has yet to be accomplished.

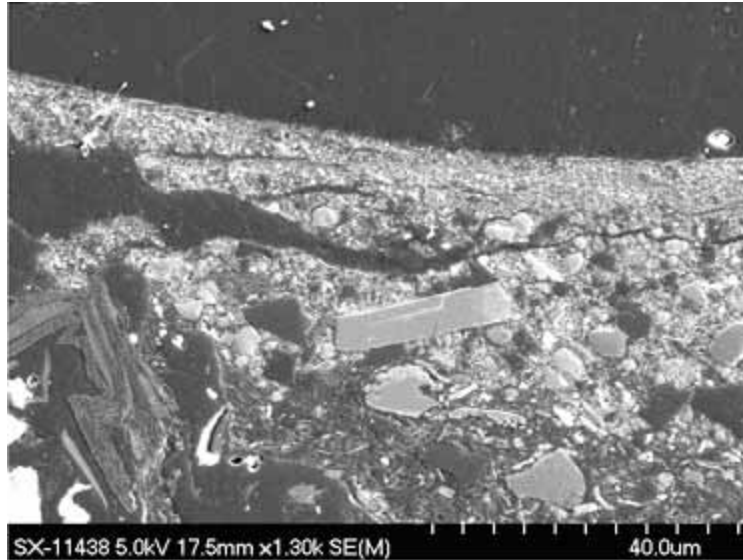


Figure 3. Thin layer of transfer **film** peeling off a brake lining from a line-haul trailer after four years of service. Cross-sectional view in the scanning electron microscope. In this case, the layer is about 0.6 mils thick (16 μm). [Ref.: P. J. Blau (2003) “Microstructure and Detachment Mechanism of Friction Layers on the Surface of Brake Shoes,” *Journal of Materials Engineering and Performance*, Vol. 12 (1), pp 56-60.]

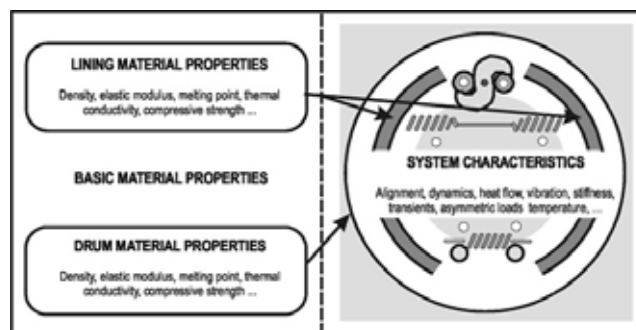


Figure 4. When materials having specific properties are included into a system, they acquire system-specific characteristics. No one has yet succeeded in predicting the system characteristics from basic properties alone.

During the latter stages of this project, we began to explore two different approaches that would eventually merge into a final recommended lining rating. The first approach was based primarily on reporting specific test parameters in some way that would be meaningful to the user. The second approach was based on identifying the lining source, stating its recommended usage, and establishing whether it had passed a standard test. In the end, a mixture of the two approaches was adopted. Issues associated with the use of current test practices will be discussed first. The conclusions made here are supplemented and supported by the analysis by Naerheim, as presented in **Appendix C**.

4.1 Potential for Using Current Lining Test Practices.

Most current brake lining material tests performed in the trucking industry involve using an inertia dynamometer, a large testing machine that use massive, spinning weights attached to a shaft that has brake hardware mounted on the end (see Figure 5). The large spinning weights are required to generate sufficient horsepower in the shaft to simulate an actual vehicle axle under load. After the weights are spinning fast enough, equivalent to the desired miles per hour, the brakes are applied either to slow down or to stop the shaft from turning (full-stop). This process results in the generation of high forces (torque) and high temperatures that are measured and recorded by a set of sensors linked to a computer. Typical inertia dynamometer tests require hundreds of brake applications under different speeds, braking pressures, and drum temperatures. Interpretation of the test results requires considerable training and expertise.

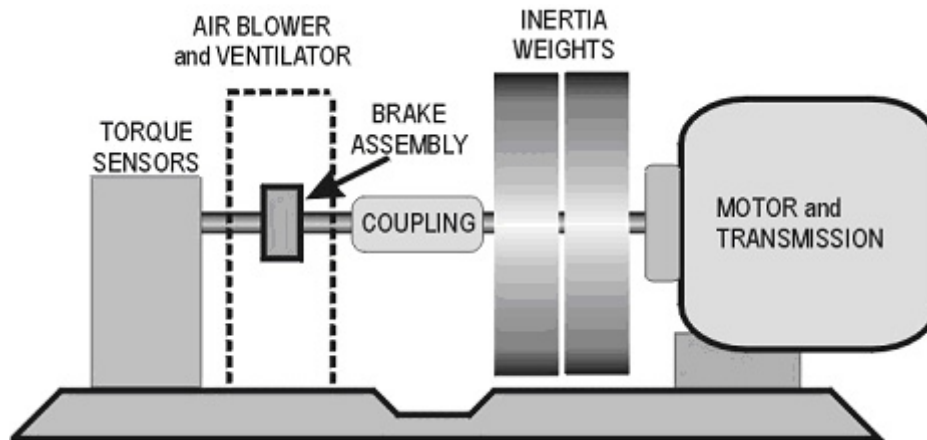


Figure 5. Simplified diagram of a typical inertia dynamometer.

Brake dynamometers must withstand a great deal of stress and get very hot during use, so they require frequent alignment, adjustments, and calibration of the force and temperature sensors. The numerous adjustments that are required make it more difficult to obtain consistent results time after time without the work of conscientious, skilled technicians. The same lining materials can produce different friction (and wear) characteristics depending on how the dynamometer is constructed and how the data is collected.

Subscale Tests. Not all of the brake lining tests that are in use involve inertia dynamometers. In fact, some tests have been developed to sit on a laboratory bench or occupy a relatively small footprint on the floor. These kinds of tests generally use small test pieces (“coupons”) cut out of linings. Some test methods were designed as a rapid way to screen experimental lining formulations. For example, A. E. Anderson developed the Friction Assessment and Screening Test (FAST) for just such a purpose. Using a small (1”x1”) square pad sliding against the face of a rotating disk, it was introduced in the 1960s and

served the need for first-cut screening very well. But it was intended by the developer as a quality assurance procedure, not to correlate exactly with the performance of the same material on a car or truck.

In the Chase test (SAE J 661), a small lining sample is slid against the inside of a rotating drum under a set downward force applied through weights. That test can also be used to screen materials. While it has some characteristics of an actual brake shoe and drum system, it is sufficiently different that friction and wear values from the Chase test do not directly predict performance on vehicles. Together, the Chase test (SAE J 661) and SAE Surface Vehicle Recommended Practice J866 “Friction Coefficient Identification System for Brake Linings” form the basis for lining code letters, dividing the friction coefficient range into seven parts as follows:

<u>Friction coefficient</u>	<u>Designation letter</u>
up to 0.15	C
over 0.15 and up to 0.25	D
over 0.25 and up to 0.35	E
over 0.35 and up to 0.45	F
over 0.45 and up to 0.55	G
over 0.55	H
unclassified	Z

Despite the test method’s questionable relationship to on-vehicle performance and disclaimers printed within the document itself, certain States and municipalities continue to use SAE J866 as a basis to specify linings for fleets of vehicles. As Greening points out in his talk (Appendix B), the following note appears in the Scope statement of SAE J 866:

“Note – it is emphasized that this document does not establish friction requirements for brake linings, nor does it designate significant characteristics of brake linings which must be considered in overall brake performance. Due to other factors that include brake system design and operating environment, the friction coefficients obtained from this document cannot reliably be used to predict brake system performance.”

It is clear that subscale tests do not provide the lining material with the same “surroundings” that it would see in a real truck. Therefore, while subscale tests might help in first-cut lining screening, they have been criticized by brake engineers as not providing test results that mimic lining performance on the vehicle.

Irrespective of the argument that the Chase test does not simulate vehicle performance, some of those who attempt to use the SAE J 866 edge codes to select linings complain that the various divisions C, D, E, etc., do not provide a narrow enough distinction to allow them to differentiate between the levels of friction they require for different kinds of vehicles.

Descriptions of several brake lining tests and marking standards are given in **Appendix D**. Certain lining test practices for drum brakes, like SAE J 1802, FMVSS 121, and TMC RP 628 (which is derived from the dynamometer portion of the FMVSS 121 test) are in relatively widespread use, but they are not without detractors. Some critics argue that the repeatability of the results, particularly SAE J 1802, is suspect because relatively small maladjustments during the set-up and differences in the aforementioned mechanical characteristics of different inertial dynamometers can bias the results.

It is known that worn-in brakes provide different responses than new, unused brakes. *Burnishing* is the term used to represent the intentional application of a test brake many times (sometimes several hundred times, depending on the selected test method) to impart the new brake with characteristics of a worn-in brake. The selection of burnishing procedures for J 1802 was also an issue. Round-robin testing

programs (that is, the same samples and hardware were sent to different test organizations) and analyses of the repeatability and reproducibility of the J 1802 test results left a number of complex engineering issues still to be resolved.* Questions remain as to whether differences in data were due to the machine, the operator's technique, or a variation in the material characteristics from one sample to another.

One of the problems with using TMC RP 628 is that no statistical variability information is provided in the PRI compilation of lining torque values. For example, if a torque value were reported as 45,960 in.-lb., what are the statistical confidence limits on that value? Due to test-to-test data scatter, is this value statistically the same as a value of 46,350? In other words, is the performance of those two linings really different? Financial issues aside, six or more repeated tests of each lining type would be needed to obtain a reasonable measure of that variability (confidence limits).

One fleet maintenance vice president complained that he needed a better way to select linings for a narrow torque operating range so that replacements could be better balanced on specific vehicles. One brake-testing expert expressed concerns that certain dynamometer test quantities, like the maximum torque, could be skewed by the way that some dynamometers mechanically apply the load. Some of them show a torque "spike" upon application of the load and others have a spike just before releasing the load. Automatically picking these spikes off the test record to define the maximum torque limits could produce biased and unrealistic torque values.

The larger the differences in the physical size, contact conditions, heat flow, and surrounding environment, the harder it is to make a testing machine behave toward materials as if they were inside the real thing. Experienced wear researchers study the surfaces of the test materials to verify that they are being worn by the same surface degradation processes in the test machine as in service. In fact, matching the mechanisms of material loss is one method to assess the quality of a laboratory-scale wear simulation.

As indicated earlier, the disc brake community is farther advanced in the development of standard testing practices in part because the pad/rotor geometry is simpler to handle than the shoe-drum geometry. Most modern automobile designs and straight trucks in the U.S. use hydraulic disc brakes. Furthermore, widespread use of disc brakes in the European trucking community has prompted more aggressive industry attention. Consequently, development of the new marking code should accommodate disc needs as well as those for traditional S-cam drum brakes.

4.2 Need for Modified or New Practices.

In the current industrial and economic climate, it would be both difficult and costly to undertake an extensive, new program of brake lining test method development. And even if it were undertaken, there could be no guarantees of success. Despite the aforementioned drawbacks in current brake lining testing practices, there is so great an investment in them that the brake industry understandably resists changing them. It may, however, be possible to modify current practices such as FMVSS 121. Extensive revision or new test development are unlikely to be pursued in these tight economic times. Some detractors advocate scrapping the entire qualification system and starting over, but this dramatic abandonment would leave the industry without any measurements of brake performance whatsoever.

With the exception of Chase-type laboratory tests in which wear is measured but typically not disclosed,

*R.L. Hoover, J. G. Howe, M. A. Flick, and D. A. Dashner (2000) *S-Cam Brake Effectiveness Comparison Using Two Fixtures and Two Lining Types on a Single Inertia Dynamometer*, NHTSA Report, DOT HS 809 162, 104 pp.
C. C. MacAdam and T. D. Gillespie (1998) *Determining the Mechanical Sensitivities of an S-Cam Brake*, NHTSA Report DOT HS 808 974, 120 pp.

standard drum brake tests provide no meaningful indication of lining wear. While wear and durability tests of different kinds exist in the brakes industry, the consensus among lining producers is that such tests, as presently conducted with full-scale dynamometers, are too expensive for widespread use. There are technical reasons as well. Users of linings subject them to different usage patterns; therefore, the mileage before replacement due to wear cannot be guaranteed by the manufacturer. Consider a driver who brakes lightly on relatively flat terrain and one who stands on the brakes while driving in hilly country. The number of brake applications per mile, the speed change per application, the duration of an application, and the apply pressure vary considerably from one vocation and one driver to another, as well as the temperature and weather conditions. Aggressive road salts can produce removal from service due to rust-jacking. No lab or dynamometer test can simulate all these things reliably.

Spectrum Tests. There is no such thing as a “standard usage profile” for a truck brake, but it may still be possible to design a series of tests that simulates the kinds of conditions imposed on brake lining materials for given classes of use (vocations). For example, in aerospace research laboratories, fatigue tests have been designed to simulate the stresses imposed on materials used in different mission profiles, like cargo plane, bomber, interceptor, etc. The same kind of approach could be used to tailor test methods to the intended use: normal, hilly terrain, school bus, etc. Tests of this kind can be designed to use laboratory-scale rigs with computer control to ensure that each spectrum test is replicated.

The discussion in **Appendix C** advocates spectrum-type brake tests in which the test protocol is selected to match the intended use of the vehicle. This approach is felt to be the most desirable, long-term solution for brake lining qualification since it enables automated screening under controlled conditions tailored to the expected conditions of use. As noted in the appendix, before any such methods can be put in place, it will be necessary to develop brake usage profiles (“spectra”) for each of several usage classes to select the correct laboratory test sequence to simulate them and to conduct experiments to correlate the two.

The use of spectrum tests depends on the availability of data. Fortunately, a current project sponsored by NHTSA is acquiring braking pressure data for 50 trucks, each with over 300,000 miles of operation, and that should form an excellent basis for the development of initial spectrum test protocols.

4.3 Development of a New Drum Brake Lining Wear Test at ORNL.

One possibility for a relatively simple lining wear test is to use the existing Chase Test (SAE J 661), which has been performed internationally for many years. That test requires cutting up a brake lining into test blocks and running them on the inside circumference of a cast iron, simulated brake drum. Wear measurements of the lining are done by weight change and dimensional change. While the standard practice requires no wear measurement on the cast iron counterface, this is sometimes done as well.

A new approach, developed in the course of this project, avoids having to cut up the brake lining in small coupons. Rather, a spinning cast iron puck is forced against an actual brake shoe to wear a divot into the surface. Several tests can be conducted on the same lining sample. The test apparatus was designed to be relatively compact, inexpensive, and easy to replicate. It also has in principle the ability to measure the effect of the lining material on the cast iron counterface, an important consideration when assessing the “aggressiveness” of a lining material.

Thus, the philosophy that we used to design and build a lining wear test apparatus involved the following:

- (1) The test should be straightforward, inexpensive to run, and use an inexpensive testing machine that can be mass-produced.
- (2) Test results should be repeatable and reproducible between machines of the same type.

- (3) Test results should correlate with field experience on specific linings.
- (4) The test method should lend itself to standardization by SAE, ASTM, TMC, or another organization.
- (5) Both lining and counterface wear resistance should be measurable using readily available inspection tools.
- (6) The test should be capable of being run with minimal operator training and take less than a single shift to complete, running mostly unattended.

Figure 6 shows the lining wear test apparatus we constructed. It was completed in August 2003, and an invention disclosure has been filed. Design, operating details, and representative lining wear data from using this apparatus will be presented in a supplementary report. Initial results using commercial S-cam drum linings with different TMC RP 628 torque ratings are encouraging, but more data must be collected and the results analyzed before a set of conclusions as to the viability of this simple test will be possible.

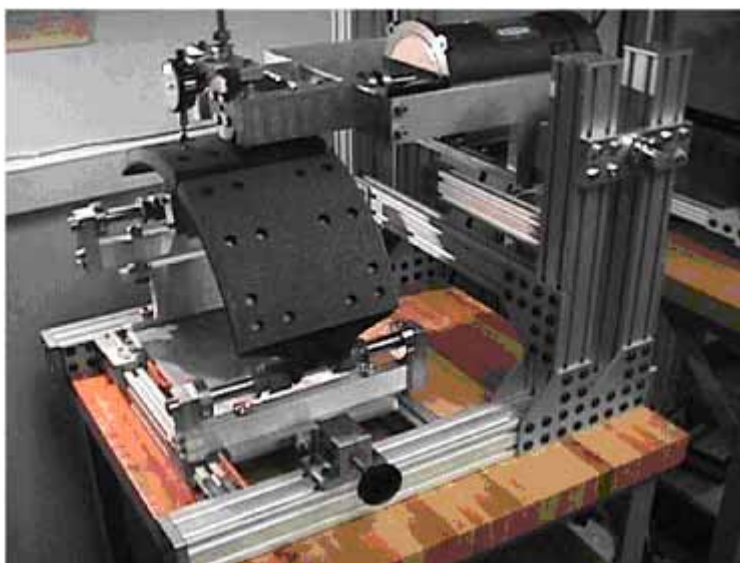


Figure 6. Brake lining wear testing apparatus that was completed in August 2003.
(Metals and Ceramics Division, Oak Ridge National Laboratory)

5.0 Proposed Lining Marking Code

After presenting numerous revised strawmen for review, and based on iterations and discussions with industry engineers and fleet operators, a proposed lining marking code structure has been suggested. This designation, which would be displayed on the lining itself or printed on its shipping box, is based on a need to identify the service conditions, the producer of the lining material, the producer's product designation, whether the lining has been tested according to Federal standards, and if so, what specific torque ranges the performance falls within. This approach carries with it a need to educate the industry on its use and a long-term obligation to maintain a database of lining test results so that the full set of test data need not be contained somewhere on the lining.

Original equipment linings will need to be identified using the same code. How can one match an aftermarket product to the new one if the new one does not use the same code? Therefore, it is proposed that all original equipment (trucks and trailers) contain documentation regarding their

original brake linings. Lining codes, specific to each axle, could be marked somewhere on the vehicle cab, included with the registration paperwork, or included in the electronic control unit. Details remain to be determined.

The need to meet pressing trucking industry needs, even in light of the shortfalls in current lining testing methodology, required us to develop both a near-term and a long-term strategy. *The **near-term plan** uses results from current test methods, namely those based on FMVSS 121, with which the industry is already familiar.* If the industry decides to do so, this near-term plan can be implemented without the need for new lining tests or other qualifications. But since future changes in lining evaluation methods are likely, the lining marking plan described here has been designed with the flexibility to be modified later if new or improved test methods are developed. The basic structure of the marking code would not change, but certain designations within it would be changed to embrace improved test methods if and when such methods come into use. The development of new test methods is a key part of the second, long-term plan.

5.1 Symbol Groupings, Description, and Rationale.

The structure of the proposed lining marking code consists of five symbol groupings separated by dashes. They are placed in a sequential order so that information needed for the initial selection is first, then information about the manufacturer, product designation, and performance in standard tests follow. That sequence is intended to facilitate computerized database searches of the product attributes embedded within the lining marking code. The five symbols groups comprising the code are:

- **Symbol Group 1. Brake Design and Gross Axle Weight Rating**
- **Symbol Group 2. Type of Service (Manufacturer's Recommendation)**
- **Symbol Group 3. Manufacturer Designation**
- **Symbol Group 4. Manufacturer's Product Code**
- **Symbol Group 5. Qualification Test Method and Selected Results**

The details and rationale for these five marking groups follows, as does an example.

Group 1. Brake Design and Gross Axle Weight Rating. These are the first things one would want to know about a lining: its design configuration and the axle weight for which it was designed. M = drum brakes, X = disc brakes, and other symbols to distinguish design variants may be added later. It might be argued that there was no need to identify the design because it would be obvious when looking at the product. However, the brake design code will also be helpful in avoiding confusion when examining lists of product codes, shipping boxes, or catalogues. For example, if it becomes desirable to distinguish hydraulic from air disc, other symbols could be added.

Group 2. Suggested Service Code (optional). This symbol grouping consists of one or more letters to indicate any special types of service for which the product is recommended by the manufacturer. For example, "H" refers to mainly highway driving or long-haul, "R" refers to regional service with more stop-and-go driving than long-haul service, "T" refers to high-temperature service as is experienced with the frequent stop-and-go operations of buses or trash haulers, and "A" refers to severely abrasive or corrosive operation as might be found in off-road conditions like farming, construction, or mining environments. Additional categories could be defined as well. For example, very cold weather service could receive its own code if there was sufficient need to do so.

Group 3. Manufacturer Designation. After examining several possible ways to designate the lining manufacturer, it was decided to use an existing industry-wide standard. This standard, five-letter supplier code is part of the system known as Vehicle Maintenance Reporting Standards. VMRS is a structured coding system for parts manufacturers and suppliers. Begun in 1970, it is maintained by the ATA's TMC. VMRS provides standard identifying codes for vocational vehicle uses, causes for

maintenance problems, commercial suppliers, and numerous types of truck parts. Recent enhancements enable linking supplier names to Dun & Bradstreet company identifiers. Code Key 34 of the system lists five-letter parts supplier designations. An example of some of the hundreds of supplier codes is given in Table 2. Clearly, using the VMRS is preferable to inventing a new system to designate lining manufacturers. Any lining manufacturer who wished to be included in the marking code but does not have a VMRS identifier would have to obtain one; however, the major U.S. lining makers are already in the VMRS.

Table 2.
Examples of VMRS Codes.

Manufacturer	VMRS Code Key 34 Designation
Abex, American Brakeblok Division	AMRBR
BBA Friction, Inc.	BBAFR
Bendix	BENDX
BrakePro, Ltd.	BRKPR
Carlisle Corp.	CRLSL
Federal Mogul	FDRMG
Haldex Corp.	HALDX
Performance Friction Corp.	PRFRM

If a company is bought or sold and hence changes its name, VMRS tends to track this. But even in that case, the Group 2 designation may also need to be changed. In order to ensure consistency in product tracking, any change in the manufacturer code should, in principle, require a product retest, even if the formulation and processing method stay the same under that new company name. It will therefore be the responsibility of the supplier to indicate in its literature (or packaging) that the new product code, with its new VMRS, replaces the previous one.

Group 4. Product Designation. This designation is assigned by the manufacturer and contained within a marking code database (see Section 5.5). It may consist of up to five alphanumeric characters. If a manufacturer changes a formulation or method of processing, the previously assigned product designation may not be used. That requires new testing and a new designation. For example, a new product ABC12 could be reformulated. The shipping box could be designated “replaces ABC11” but the item itself must be marked with a new designation that is traceable to the database of product test results (see Group 5).

Group 5. Qualification Test Method and Results. The content of Group 5 will probably elicit the most debate since it is based on selected quantitative measures of lining performance. It can be argued that almost any metric for lining performance has advantages and disadvantages. Clearly, the use of standard test methods has advantages, but as emphasized earlier, complex dynamometer-based standard tests have room for technical improvements.

Which metric to choose. Most brake lining tests generate a lot of data even for one combination of lining and drum. Tables of data from a single test can contain hundreds of numbers. Therefore, a primary challenge is to distill the complex dynamometer test results into a just a few metrics that are understandable and suitable for the marking code. This problem is made even harder considering that, depending on which numbers are picked out of the tables of brake test data, linings can be ranked in different order of merit. For example, one could pick torque values for any of several braking temperatures (IBT) or air line pressures. Therefore, selecting just one or two metrics from a host of possibilities necessitates making a compromise and does not represent a comprehensive description of lining performance under all kinds of conditions.

In the near-term marking plan, Group 5 was given three identifying characters. The first designates whether the product has passed the dynamometer portion of the FMVSS 121. A “P” indicates passed FMVSS 121. The second and third numeric characters are used to indicate torque levels for normal and emergency braking, respectively. It should be emphasized that the actual braking force that results from these reported torques is affected if the design of the brakes is different than the hardware used in the dynamometer fixtures (for example, different slack adjuster length, tire rolling radius, and air chamber size – see the equation given in Section 4.0).

Numerical characters are used for indicating torque levels to avoid any confusion with the previous edge codes (from SAE J 866) that use letter designations for friction levels. The first numeric character in the group indicates the torque range into which the 20-psi braking pressure data from the FMVSS 121 dynamometer test falls. Likewise, the second numeric character indicates the torque range into which the 80-psi, high-braking pressure, falls. Additional analysis of existing data will be needed to establish relatively narrow ranges, but the width of these torque ranges must be selected on sound technical grounds. Therefore, it is recommended that all FMVSS 121 data for “P”-rated linings be archived in an open, publicly accessible database. Informed users can then obtain additional information about such lining characteristics as “fade,” but that will require educational materials to accompany the database.

5.1.1 Considerations in Identifying Torque Ratings for the Second and Third Characters in Group 5.

Some of the difficulties in trying to represent performance with a letter code surfaced during the use of the friction material “edge codes” (SAE J 866). It was claimed by certain fleet operators that the friction coefficient ranges designated by A, B, C, etc., were too wide, and consequently did not provide narrow-enough product differentiation. In consideration of this short coming, coupled with deeper concerns that the tester did not sufficiently mimic actual brake characteristics, the SAE Brake Linings Committee has, for several years, tried to withdraw this marking standard, but purchasing agents for certain State government vehicle fleets want to use it, and they push to keep it on the books.

The SAE Performance Review Institute (PRI) requires three repeat tests of each lining material, using an approved dynamometer, to obtain the TMC RP 628, 40-psi torque values it publishes. Torque values for more than 60 lining materials are currently listed by PRI. These are broken down into two GAWR categories and the average torque values are shown to five significant figures in the table. While a three-test average is better than one test, the question still arises: How much statistical variability is there in these torque values? PRI’s literature contains qualifying statements regarding the approximate nature of the data and the responsibility of the user in making selections based on the tabulated values. Yet this question of variability has implications when attempting to subdivide the range of torques into smaller ranges that can be letter-coded on a brake lining.

A plot of the reported torques (available on the Internet) reveals a range of values for nearly 50 linings (see Figure 7). All the data falls between 45,000 and 80,000 in-lbs. The availability of error bars for the data would show whether it would make sense to divide the entire range into sublevels. For example, is a lining with an average torque of 59,280 in-lbs really different than one with an average of 58,598 in-lbs? If one lining is just high enough (say 10 in-lbs above the cut) to fall into a higher torque category, is another one that just misses the cut by 10 in-lbs really inferior in stopping performance?

Figure 7 shows the large range of torque values obtained for almost 50 linings. Considering linings in the 17,000-to-20,000-lbs GAWR category, and arbitrarily dividing the data into ranges of 5,000 in-lbs, the resulting distribution is shown in Figure 8 (see also the presentation by J. Clark in Appendix B). The average is 54,224 in-lbs, a value very near the split between two of the ranges, and the distribution is relatively even, displaying similar numbers of linings in each range. When dividing the data into narrower 3,000-in-lb ranges, the distribution appears even less uniform and shows that a large number of

linings fall within the 48,000-to-51,000-in-lb range (Figure 9). Separating torques into categories requires a decision on how narrow the ranges should be in light of the typical variability of the data. Wide categories would be more tolerant of the test-to-test variability in results, but a narrow range would enable better discrimination, at least in principle. The full data spread for 20-psi and 80-psi control line pressures must therefore be analyzed in order to make a rational determination.

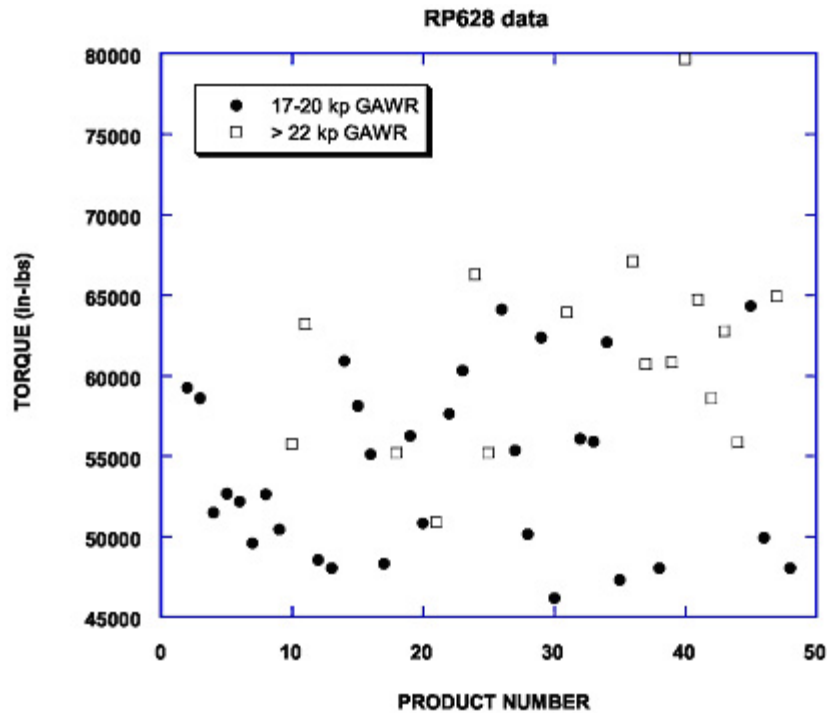


Figure 7. 40-psi torque data for almost 50 linings (Source: PRI Web site on the Internet).

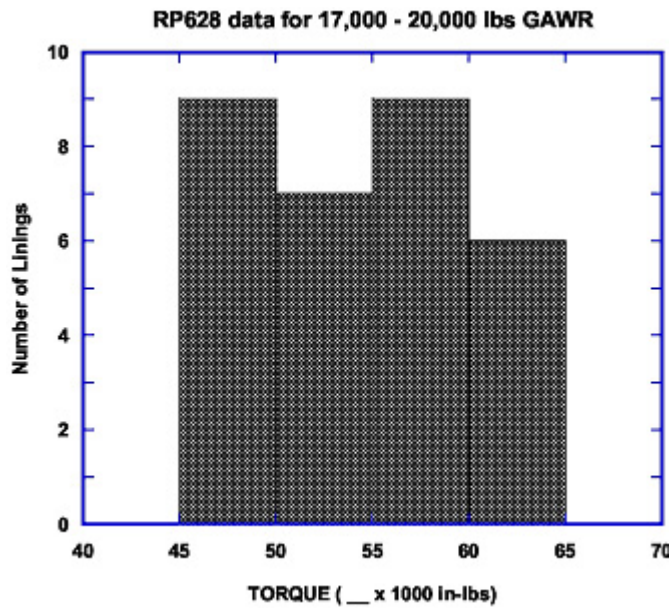


Figure 8. RP 628 torque values separated into 4 ranges, each 5,000-in-lbs wide.

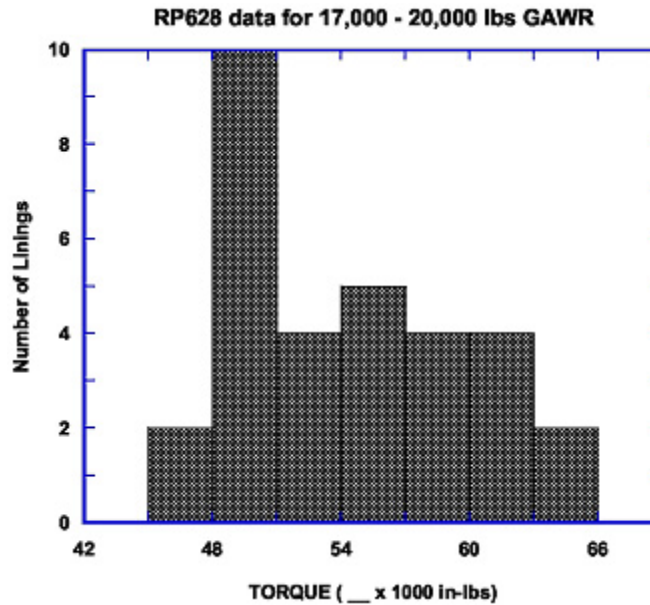


Figure 9. Subdivision of RP 628 torque data into 3,000-in-lb ranges.

5.1.2 Fade.

The term “fade” refers to a reduction friction coefficient at elevated interfacial temperature, such that it requires more force to retard the vehicle when the brakes get hot. This characteristic is important to control in vehicles that normally run with hot brakes (buses, trucks in mountainous terrain, garbage trucks that stop once every 20 seconds, etc.). Information related to fade is present in certain parts of the FMVSS 121 data. For example, consider the “Brake Power” segment of the procedure [§ 5.4.2], summarized as follows (see **Appendix D**):

Begin with 125° F ♦ IBT ♦ 200° F for the first application. Then,

- Conduct 10 decelerations from 50 to 15 mph at 9 ft/s² at equal intervals of 72 s counting from the start of deceleration of the previous application. (Line pressure not to exceed 100 psi for any application.)
- After last deceleration and running at 20 mph, decelerate to a stop at 14 ft/s².

FMVSS 121 dynamometer “brake power” test data for several lining materials can be mathematically represented as a second-degree polynomial of the form:

$$MP = m_0 + m_1 T + m_2 T^2 \quad (1)$$

where T = brake temperature (°F), MP = maximum air line pressure (psi), and the m’s are coefficients to fit the data to a curve.

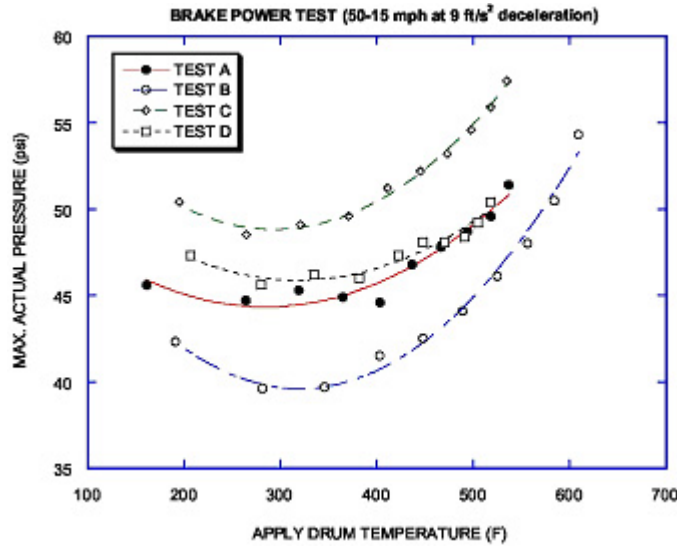


Figure 10. Plot of actual brake power data for several RP 628 tests.

The parameters calculated for four actual lining tests (plotted in Fig. 10) are shown in Table 3. The correlation coefficient (R) is one measure of how closely the data fits the curve. In this case, the fit is reasonably good (R = 1.000 is a perfect fit). Taking the first derivative of equation (1), above, and setting it equal to zero allows us to compute the minimum value for each curve. These range between 285° and 320° F. Warm drums (around 300° F) require less pressure to brake than either cooler or hotter drums.

2 nd degree fit to data	A	B	C	D
m_0	52.65	56.35	61.19	56.42
m_1	-0.0584	-0.1047	-0.0842	-0.0664
m_2	0.000103	0.000164	0.000143	0.000104
R (correlation coefficient)	0.972	0.994	0.996	0.971

Table 3. Second-Degree Curve Fits to Brake Power Test Data.

While the mathematical parameters in Table 3 replicate the four curve shapes very well, they do not provide a direct sense of the fade performance. On the other hand, the difference between the minimum value, which falls at about 300° F, and the value at 500° F indicates how much more line pressure is needed to account for the fade-induced frictional fall-off at higher temperatures. Table 4 shows these values. On that basis, lining C has the most fade and lining D has the least.

Table 4. One Possible Measure of Fade.

Lining	Pressure at 300° F	Pressure at 500° F	Difference in pressure (psi)
A	45.1	49.1	4.0
B	42.0	45.0	3.0
C	50.1	54.9	4.8
D	47.3	49.3	2.0

A range of only 2.8 psi between the four different linings is not very big, and requires accurate calibration of the testing equipment. Clearly, a wider range of data, encompassing ‘good’ and ‘bad’ linings, must be examined. Dynamometer test data can be used to indicate fade, but the additional calculations might be too involved to include within a simple and understandable lining code number.

5.2 Marking Code Example.

Table 5 summarizes the proposed near-term lining marking code plan and the various segments of numbers and letters that comprise it.

**Table 5.
Summary and Example of the Proposed Lining Marking Code**

	BRAKE DESIGN	MAXIMUM GAWR	SERVICE CODE(s)	MANUFACTURER IDENTIFIER	PRODUCT IDENTIFIER**	FMVSS 121 DYNO RESULTS*
Number of letters or numbers	1 upper-case letter	2 numeric characters	1 or more upper-case letters	5 upper-case letters	up to 5 alpha-numeric characters	1 to 3 letters or numbers
Explanation	brake type	maximum gross axle weight rating	Indicates type of service that is recommended by the lining manufacturer	5-letter symbol that uniquely identifies the manufacturer	code used to identify specific product.	indicates FMVSS 121 dyno test torque ranges for 20- and 80-psi tests
Codes	M = drum type X = disc type Note: combines with the second digit cluster (no dash between them)	Maximum GAWR in thousands of pounds	H = normal highway use R = regional service T = high temperature service A = severely abrasive, off-road service	Standard codes for manufacturer identification from the VMRS system.	Each manufacturer registers a specific product identifier of up to 5 letters or numbers. Examples: “CMD16,” “AR2”	P = passed FMVSS 121 2 nd digit = range for the 20 psi torque value 3 rd digit = range for the 80 psi torque value
Example	M	22	HR	JONES	AB20	P23
Explanation of the Example:	the lining is intended for drum brakes	intended for GAWR up to 22,000 lb.	The manufacturer recommends this product for either highway or regional service	(hypothetical) symbol that identifies Jones Brake Co. as the material producer	(hypothetical) code for a certain product that is registered to the Jones Brake Co.	Passed FMVSS 121; torque fell into range “2” for 20 psi, and range “3” for 80 psi

Using the format shown in Table 5, the following is how the hypothetical lining marking code, shown in the example at the bottom of the table, would appear:

M22-HR-JONES-AB20-F23

5.3 Durable Marking Methods

Marking lining codes physically on the brake linings is a serious problem. There are two reasons to mark the codes on the linings directly: (1) to identify them from stock and to ensure the correct linings are provided when purchasing new lining products, and (2) to enable the maintenance technician to properly match the old lining with its replacement.

A number of methods are available to mark new linings; however, there is a major challenge for marking brake linings in such a way that they can survive the harsh environments of the road. Sophisticated methods might be devised, but their cost may exceed the cost of the lining product itself, making such methods impractical. Six methods of marking linings were considered. Most of them would serve to identify new linings, but all have drawbacks when it comes to long-term survival in service.

5.3.1 Painting. Most brake linings currently come with a manufacturer's designation marked on the side. This is essentially done by an automated jet-spray painting process. Exposure to dirt and road conditions tends to make such markings unreadable by the time that the lining must be replaced. Color coding would generate similar concerns. An alternative scheme would be desirable to ensure that the lining marking code will be readable at the time of lining replacement.

5.3.2 Tag embedment. A corrosion-resistant metal tag (stainless steel) could be embedded in the lining material, but it should not be placed in a location that is worn down (like the edges). Locating the tag in a less exposed location would probably mean it would be harder to find by those seeking to match the lining with a new replacement. They would have to know exactly where to look. Ideally, the mark would be visible on the brake shoe as installed so that replacements could be ordered ahead of time, before the worn out shoe was removed.

5.3.3 Shoe table stickers. Water-resistant adhesive stickers could be affixed to the steel shoe table. Strong adhesives like those used on license plate renewal decals might be considered. However, the adhesion of such stickers in the face of frictional heat generated during braking will require testing under road conditions.

5.3.4 Shoe table stamps. An alternative to painting would be to stamp the marking on the steel shoe table, but that would also mean that the reline would have to match the shoe table stamp. If it did not or if reused tables got mixed up, there would be a good chance of mixing up the linings as well.

5.3.5 Electronic tags. Electronically embedding a tag into the lining, similar to the method that has been used to identify pet dogs and cats, was investigated. Electronic inventorying of tires by embedded chips has been done, but that requires special tag readers and detailed bookkeeping. E-tagging methods could eliminate the need to use a marking method that might rub off during use. However, upon investigating this further, it was discovered that for the kind of implantable tags used with pets, the heat generated during braking would render them inoperable (maximum operating temperature under 200° C).

5.3.6 Notching. Since wear-and-tear can make a painted or stamped lining code unreadable, the possibility of cutting an identifying series of notches, like a bar code, into the side of the lining or shoe table was considered. This also presents problems for several reasons. The number of notches to fully encode the proposed marking scheme would be large. In addition, there exists the potential for defacing the notches or producing additional notch-like features during handling or by corrosive attack by road deicing salts.

One option is to not mark the linings at all, but include a paper or metal tag with the product. That could lend itself to mix-ups or loss during shipping or relining. Additional engineering is needed to resolve the durable-marking and tracking issue. A workable solution is not obvious at this point.

5.4 Education of the Lining Producer and User Community

Consumer education is an essential component of any complex technically based society. Any new marking system, no matter how simple and straightforward, could be met with resistance and, even if accepted, will require education. Freely available educational resources should make it possible to educate the user community on the meaning of every part of the lining designation, including the test results. The education of rating system users could be done with a four-pronged approach:

- (a) Internet Web site containing a professionally designed tutorial
- (b) Hard-copy material for distribution
- (c) Presentations at meetings and seminars
- (d) Computer media (CD's, DVD's, diskettes)

In regard to (a), it is proposed that a Web site, possibly called the "Truckers Automated Brake Lining Evaluator and Selector" (TABLES) be developed, providing a gateway to access organized brake lining product test data and serving also as a means to educate users of the new marking system.

5.5 Data Repository and Maintenance

The group that would establish and maintain the lining test and marking database remains to be decided; however, preliminary discussions with the TMC of ATA have indicated its interest. The testing information to populate the database might be obtained from the SAE/PRI Brake Committee, which already collects data from the FMVSS 121 dynamometer test to support RP 628.

Perhaps the initial database establishment could be supported by the Federal Government. Once it is established, it would be a matter of inputting additional test data as it becomes available and making this data available in a searchable format. The same or a second organization would be required to maintain the marking code educational resources to educate users.

[Note: Automobile and light-truck lining certifications are progressing somewhat faster within the industry. In November 2002, the Brake Manufacturers Council announced a voluntary automotive aftermarket lining certification program. The Brake Effectiveness Evaluation Program resulted from a decade of development and is intended to provide consumers with an added indicator of product quality. Seals are placed on linings that pass the voluntary test procedure. (See additional details in T. Duncan's presentation in **Appendix B**.) There is also a voluntary D3EA industry program that enables the effects of front-rear brake interactions to be evaluated simultaneously. It uses a special-purpose, dual-ended dynamometer and correlates the results to standards FMVSS 105 or 135, as appropriate. (See additional details in C. Greening's presentation in **Appendix B**.)

5.6 Establishing a Gateway to Lining Data and Consumer Education.

TMC, or whichever organization assumes responsibility for hosting the lining database, should also be responsible for continually updating it, maintaining the integrity of the data, and enabling free access to it by the trucking community.

An organization that develops educational software could be contracted to work with ORNL and the Web site host to develop educational materials for lining selection. Such educational software could

probably be completed within a year. As an Internet resource, such information could be accessed by a laptop computer from truck stops, maintenance depots, or on the road by wireless communications links.

6.0 Summary and Discussion of Possible Future Efforts

Balance and compromise. In order to develop a useful lining marking code, it was necessary to balance a number of concerns from different parts of the brake user and supplier community. A convenient near-term marking code and an improved, long-term strategy were developed in this report. Both are compromises among simplicity, flexibility for future change, technical correctness, and practicality.

Marking code structure. The basic marking code, both near-term and long-term versions, contains five symbol groupings. These encompass brake design, axle weight rating, intended service use, manufacturer identifier, product designation, and performance metrics. The first four groups are not expected to create as much controversy as the fifth one. The performance indicators suggested for the short-term implementation are based on existing safety standard FMVSS 121 that was primarily designed for 16.5" x 7" S-cam drum brakes for new Class 8 trucks. This limits its usefulness somewhat for categorizing other brake designs and sizes. Future changes to the lining code to use more application-specific tests will not require changes to the basic structure, just the designations used for the fifth grouping of characters. Any changes will require educating the consumers at that stage. Disc brakes, both air and hydraulic, could be accommodated using the basic lining code structure, but the test method embodied in Group 5 would be different since disc brakes behave differently than drum brakes.

Current lining tests. Certain drawbacks were noted in the way in which dynamometers are used to perform standard tests. These involve numerous adjustments, calibrations, data filtering criteria, complex sequences for burnishing, and metrics for brake effectiveness. With such inherent complexity, variability in the repeatability and reproducibility of results is not surprising. To truly test the material characteristics, and not also the behavior of the testing machine itself, it is necessary to reconsider the methods for testing that focus on simpler, more controllable configurations. Therefore, the longer-term strategy requires tailoring the lining test method to simulate specific operational spectra of different vehicles and brake types and matching the test method to the intended use for the lining. That course will require a considerable investment in research and development. A well-engineered lining material tester could be computer-controlled to simulate different braking usage spectra.

Simplicity, archiving, and education. The near-term lining marking codes are simple to explain and use. They will require an organization to maintain up-to-date lining test data, much as the SAE PRI does today. It will also require a proactive educational effort to ensure that the markings are used correctly.

Omission of a measure for wear. There was no measure of wear-resistance included in the proposed lining rating despite an expressed desire on the fleet operators' part to use wear as means to see if the cost of a premium lining is justified. Providing a wear metric was not favored by lining suppliers even though they routinely perform such tests internally to develop product formulations. ORNL built and evaluated a relatively simple lining wear testing apparatus that consists of a small cast-iron puck spinning against a lining surface. This apparatus is intended to measure both the lining wear against cast iron and the wear of the cast iron, as a measure of lining abrasiveness. Preliminary tests are underway to evaluate its ability to discriminate between different variants of lining material. Those results will be reported at a later date, as will the potential for standardizing this relatively simple, inexpensive procedure.

Suggested Future Activities

Based on these findings, eight possible future research activities have been listed. Five pertain to the near-term code and the last three to the longer-term solution. Some of these future activities could be

initiated using the remaining project funds (for example, items 2, 4, and 6). Others will require additional investments in funding. Suggested follow-up activities and levels of effort in person-years (PY) are indicated in brackets []. Working partnerships and commitments on the part of the trucking industry and its suppliers will be key in the implementation of any future research. Therefore, the time needed to implement this will depend, to a degree, on the level of commitment and follow-through by industry partners.

1) ***Initiate a Tracking Program for Brake Linings Supplied With New Trucks.*** Truck manufacturers will be asked to provide information, axle-by-axle, on the lining types with which they supplied the original vehicle. This information should be carried on the vehicle, for example on a door jamb sticker or a code in the electronics control unit. Information will contain the proposed lining code. The method for marking the code on the vehicle, and the linings themselves, needs to be determined.

[1.1 Determine how to implement a practical method for tracking the lining type provided on new trucks and trailers. 1 PY effort for 2 years.]

[1.2 Investigate practical methods to physically mark brake linings so that the code is still readable when a replacement is required. 1 PY effort for 1 year.]

2) ***Review Dynamometer Data.*** The near-term version of the marking code uses torque data obtained by the FMVSS 121 dynamometer test procedure under two apply pressures (20 and 80 psi). This data should be obtained for a variety of current lining products to determine how many different torque levels (1, 2, 3, 4, etc.) are technically justified to be used for code segment (f).

[2.1 Contact sources of FMVSS 121 lining data to obtain 20- and 80-psi torque data for a variety of linings. Analyze the range and distribution of these data to help select the number of levels into which the data are divided in marking code segment (f). ½ PY effort for 1 year]

[2.2 Conduct a more extensive evaluation of existing FMVSS 121 data to determine how the data could be clearly represented and displayed in a more comprehensive public database on lining performance. Provide the information to the developer of the educational software package (see 3.1). 1 PY effort for 1 year]

3) ***Educate Those With a Need to Know.*** Implement a trucking industry education program about the new code system and the lining data that supports it. Methods include (a) presentations to industry groups, (b) trade magazine articles, (c) free pamphlets for distribution to dealers and truck stops, and (d) Internet Web sites. The online educational effort could be funded by private industry, DOT, or both. On the basis of preliminary discussions, this educational Web site could be hosted by the TMC.

[3.1 Develop educational software for the new lining code system and implement it in hard-copy and via the Internet. ½ PY effort for 6 months, following acceptance of the lining code.]

[3.2 Continuing education on the lining code and how to use it can be done through short courses offered by trade organizations.]

4) ***Identify a Database Custodian.*** The custodian of the test data for specific linings may be a trucking industry organization like the TMC. It makes sense to have both the lining data and the educational material linked through the same Internet Web site.

5) ***Provide a Web site and Data Gateway.*** The TMC should be approached as the prime candidate to host and maintain the Web site that educates users on the new lining marking system and provides links to a lining test database that supports marking code segment (f). Ideally, the supporting database will be searchable online, based on any of the individual code segments or a combination of segments in the marking code.

[5.1 Set up a Web site and populate the supporting database with lining test data from one or more validated sources of FMVSS 121 data. 2 PY effort for 2 years.]

6) ***Continue to Develop a Cost-Effective Lining Material Wear Test.*** Work should continue on developing the relatively simple lining wear test prototyped at ORNL. Obtain additional data on several linings and investigate the degree to which laboratory wear test results agree with fleet experience with the same kind of lining. If successful, the test could be standardized either under ASTM (Committee G-2 on Wear and Erosion) or SAE (Brake Linings Committee), and additional units of the machine could be commercially produced.

[6.1 Establish the final testing protocol, then obtain any wear-test lining materials whose performance covers a range of durability. 1.5 PY effort distributed over 2 years.]

[6.2 If results warrant, prepare an ASTM Standard Practice describing the lining wear test and work through Committee G-2 on Wear and Erosion to standardize it. ½ PY effort distributed over 2 years.]

7) ***Develop Operating-Use Spectra.*** To enable the development of vocation-related test protocols, initiate a longer-term program to collect data on the operating conditions of brakes on selected vehicles. Begin with three types of vehicles: (a) line-haul tractor-trailers, (b) school buses, and (c) straight trucks for local delivery.

[7.1 Develop operating spectra for three representative vehicles through instrumenting test vehicles or accessing existing data. 2 PY effort distributed over 2 years.]

8) ***Development of a Spectrum Test Method.*** Select and develop a laboratory test system on which the operating profiles of various vehicles can be programmed and applied. This can be based on an existing test or a new system. Cost, accessibility to testing facilities, and potential for standardization should be prime considerations. In-kind industry contributions (access to facilities and technical advice) will be critical to support this effort. If successful, the data from this test will replace that used for the near-term rating code, segment (f).

[8.1 Develop test machine and conduct spectrum tests to simulate the operating profiles defined by the work following 7.1. 3 PY effort distributed over 3 years.]

Prospects of Future Brake Technology. Future braking systems will increasingly be automated. Electronic braking systems are already being demonstrated on tractor/trailer combinations. Variations in the lining characteristics between one wheel end and another, and one axle and another, can, in principle, be compensated for by such computerized systems. Theoretically, as long as the linings have adequate wear life, replacement lining materials with adequate frictional characteristics could be allowed to vary more in torque response under the expectation that the on-board computer system will maintain the proper balance of braking forces. Having the proper brake pedal feel is important to the driver. NHTSA has stated in the past that a problem with air brakes is the lack of pedal feedback that might indicate brake problems. Lining wear should not have such an effect either. ECBS would likely have condition monitoring to warn the driver of brake problems.

However, in the near-term (for at least the next 10 years), the characteristics of the lining materials will still need to be considered and selected carefully by the fleets and truck operators. The current marking system is intended to meet that need.

APPENDIX A

THE MYSTERY OF AFTERMARKET BRAKE LINING SELECTION

By Larry Strawhorn

(Presented at the SAE Truck & Bus Meeting, December 5, 2000)

What is dirty gray, curved and difficult to identify from the rest of the herd? If you guessed an elephant's back, you made the wrong choice, just like a lot of fleet people do when they select replacement brake lining. Used brake lining is a bit like Winston Churchill once described Russia, a puzzle wrapped in an enigma surrounded by mystery. We know that brake lining exists and must someday be replaced. The big question is replaced with what? Neither a new brake lining, nor one that is worn gives many clues to its actual friction level or brake block effectiveness.

The first thing I need to do is define the rating that those purchasing replacement brake lining desire. We call it the brake lining friction rating. However, somewhat like sandpaper's grit rating really doesn't identify its friction level, a similar situation is in play here. So the brake effectiveness rating that we desire is defined in SAE J1802 as the non-dimensional measurement of brake performance. It is the ratio of the brake frictional output to brake force input as determined by the SAE J1802 test procedure.

Call it what you like, we want to know that the replacement lining will cause the brakes to perform like they did with the worn out material. And we want to have confidence that the rating assigned its products by manufacturer A is measured and assigned and has the same meaning as that used by manufacturer B.

Unfortunately I cannot give you great insight into rating the friction or effectiveness of brake lining. Quite frankly that job is for those of you who are expert in such things. Important work has been started relative to this and it should be finished. I will tell you why those who maintain the nation's fleets need such ratings. I hope to impart to you why motor carriers are frustrated over the lack of such ratings to the extent that they have authorized their trade association to raise the issue in the halls of Congress.

While thousands of truck users are buying replacement brake lining using the stab-in-the-dark process, the Federal government has turned its eye toward electronically controlled braking systems (ECBS). Many see greater highway safety resulting from a high-technology redesign of the truck braking apparatus. The American Trucking Associations has encouraged the National Highway Traffic Safety Administration to tread carefully and work with the industry to develop standards for these so-called "brake-by-wire" systems, and the agency has convened a working group to do just that. We certainly support the effort.

However, NHTSA has a history of focusing its activities on development programs like this one while ignoring a basic, low-tech consumer information item that could have a significant impact on safety. Back in 1968 the agency proclaimed that rating truck brake lining friction and marking materials with this rating is important and it opened a docket dealing with this matter. In the intervening 32 years it has mandated many things including split braking systems, automatic slack adjusters and antilock braking systems. All are important and each has a self-styled safety advocate and manufacturer constituency that cheered them on to become something that must be sold on every new truck, tractor and trailer. Brake lining effectiveness rating has far fewer cheerleaders.

The fact that the move to require brake linings to carry an effectiveness rating has languished in the background, while all these new technologies are mandated tell the consumer something. They are a powerful indication that the government and some equipment purveyors are more concerned with promoting new technology than they are with improving the chance that maintenance will be done properly.

While the maintenance performed by fleets is often decried, new rules are being written that mandate systems requiring higher levels of expertise to maintain. Yet there are no standards for durability, reliability, or maintainability, all things that would help the consumer keep these systems in repair. And to this day even the best mechanics cannot tell the effectiveness characteristics of the brake lining that they remove or those of the replacement material.

This is an attitude that we hope changes. Certainly the brake valve manufacturers have addressed this issue. Through SAE J1860 air brake valves are labeled with their performance (input-output) characteristics. We can only hope that brake linings will get similar treatment.

With the mandate of ABS and advent of ECBS, computers now determine when wheel lock up is about to occur and cycle air pressure to prevent it. While this is a good thing for many reasons, the down side is that the computers have no idea of

why there is an impending wheel lock up. Also, because of this the driver has lost the “feel” that used to be triggered by wheel lock. And this leads to another reason that a brake lining rating is so important.

Many things cause brakes to lock including a wet or icy road, a worn tire with poor friction coefficient, or a vehicle with improper brake lining. However, the BS’s, ABS and ECBS, by preventing wheel lock, mask these brake problems from both the driver and the mechanic.

Today’s driver has lost the seat-of-the-pants feel of a vehicle’s braking capability. Good drivers used to sense the amount of pressure that they applied to the treadle valve and how the vehicle responded to it. The selection of replacement brake linings having improper performance characteristics is no longer readily identifiable by driver “feel.” If the ABS warning light doesn’t come on or the low air pressure buzzer sound, the driver runs on faith that the brakes are working properly.

Before the ABS’s an attentive driver could feel the affects of wheel lockup, at least on dry pavement, and smell overworked brakes. Today’s drivers, with ABS equipment, have a much harder job determining potential or existing brake problems that should be noted on their vehicle condition reports. They may not know that brake lining with improper performance characteristics is adversely impacting their brakes because electronic controls are masking the symptoms.

Brake lining friction is important. The classic equation for brake output force provides a means to compare differences in brake capability due solely to lining friction variations. In this relationship:

Brake Output Force=(A)(B)(S)(2)(D)(F)÷(C)(T) Where:

A=Air pressure used to apply the brake, in pounds per square inch
 B=air Brake chamber size, in square inches
 S=length of Slack adjuster lever arm, in inches
 D=inside radius of brake Drum, in inches
 F= brake lining coefficient of Friction

C=Cam radius of brake actuation S-cam, in inches
 T=the Tire rolling radius, in inches

A hard stop with a normal brake system can be defined as:

A=60 psi. This is a hard brake application.
 B=30 in². This is for a common type-30 air chamber.
 S=5½ inches. This is a common slack adjuster length.
 D=8¼ inches. This is for a common 16½x7-inch brake drum.
 F=.351 to .45. This is a normal friction coefficient range for an F lining.

C=½ inches. This is the normal S-cam brake cam radius.
 T=19.2 inches. This is a rolling radius for an 11R22.5 truck tire.

The variance in brake force that spread in brake friction creates is:

$$\begin{aligned}\text{Brake Force} &= (60)(30)(5.5)(2)(8.25)(.351 \text{ to } .45) \div (.5)(19.2) \\ &= 17015.625(.351 \text{ to } .45) \\ &= \mathbf{5,972.48 \text{ pounds to } 7,657.03 \text{ pounds}}\end{aligned}$$

This means that using a brake lining at the low instead of the high end of the F rating will reduce the brake output force by 22 percent. This rating is assigned according to the SAE J866 friction coefficient identification system.

The fact that such variability exists with linings assigned the same rating results from the rating method used, SAE J661. This procedure is for quality testing, not effectiveness rating. It is based on a one-inch-square sample of the lining instead of a complete brake block. As such it does not accurately represent how a full-size lining performs when used in an actual truck brake with a normal brake drum.

A different test, SAE J1802 “Brake Block Effectiveness Rating” was published in June 1993 to rate brake block effectiveness. This was to be the answer to the consumer’s desire to have a brake lining effectiveness rating. To date, however, the procedure does not give repeatable results, and therefore, it is considered still under development. SAE J1801 Brake Effectiveness Marking for Brake Blocks will be used in conjunction with J1802 to permanently mark brake blocks with their effectiveness. This marking will enable the mechanic to “read” and match the effectiveness of both the worn and the replacement linings.

Now, I do not want to leave the impression that nobody has done anything about developing a meaningful brake lining effectiveness rating. J1802 itself indicates that significant work has been done. NHTSA, through Dick Radlinski and Mark Flick, did a lot of work to come up with a means to determine the rating. And many manufacturers' engineers, especially those who design foundation brakes, but also lining and vehicle engineers worked very hard on the project. I know I will miss someone else important to this endeavor but I would be remiss if I did not mention the efforts of Jim Clark and Randy Petresh here, they worked particularly hard on this. And the Maintenance Council of ATA helped provide funding for this work because truck users are so desirous of the information.

The lining rating effort to date has two basic divisions. One part was developing the procedures in J1802 and the other involves testing those processes. Unfortunately the testing indicated that there might be problems with the procedure. The same lining tested in different locations produced a variety of ratings. This work is summarized in a Department of Transportation Report DOT HS 808974.

The variability in lining ratings led to an in-depth review of the test fixture. The effectiveness and mechanical sensitivity of the S-cam brake design was studied carefully to learn if and how it might contribute to the problem. This work was detailed, time consuming and well done. Unfortunately it did not lead to a clear picture of what may be wrong.

The effort was well organized and those involved worked hard but, unfortunately, the toiling stopped before a procedure embraced by all was developed. For the most part questions relating to the test fixtures have been answered. There is still mystery concerning whether the test or inconsistencies in today's brake lining cause the non-repeatability found when using J1802. Unfortunately the research work stopped short of reaching the goal of having a proven brake block effectiveness rating technique. And the consumer is left to wonder what replacement lining to buy.

I have some results of another testing program that indicates that we should not let this matter drop. This work was done using one of the performance-based brake testers described earlier in this session. A company that performs analyses of braking using one of the performance-based machines checked 47 owner-operator maintained vehicles for a client. The purpose of the tests was to determine the level of maintenance of these vehicles. The machine rejected 51 percent of them for having unsatisfactory brake power. Thirty-two percent had low braking power and 19 percent had power so high that there could be tractor-trailer brake compatibility problems.

Many of these vehicle's problems stemmed from brake lining with inappropriate effectiveness levels. Typically the owners of this equipment do not know how to find the effectiveness rating of the original lining. They buy what a parts distributor or repair facility sells them. And acting with no real clue from the material to be replaced, the organization selling the new linings can only guess about what is needed.

Appropriate effectiveness levels are determined by the design of the individual truck's braking system and its real-world operation. Trouble occurs when worn brake linings are replaced with those having inappropriate effectiveness characteristics. This happens more than it should because linings lack a standardized permanent effectiveness marking and there is no simple way to determine the appropriate level. To complicate matters further, newly manufactured trucks may use brake linings that are not commonly available in the aftermarket. This means truck owners do not have the option of replacing "apples with apples."

When an inappropriate replacement brake lining is used, the results can be dangerous. A lining with a low effectiveness level could lead to the truck making a long panic stop. Too high a level may result in an abrupt stop, in which the driver loses vehicle control.

One of the most common complaints of fleet maintenance professionals is dealing with this problem. And the Federal Government has consistently agreed that the problem should be resolved—but, to date, it has not been.

In 1987—almost 20 years after NHTSA, in Docket 1-4, first stated that standard friction ratings are necessary for safe operation—ATA petitioned NHTSA for a rulemaking to require standard friction ratings and permanent markings on brake linings. NHTSA granted the petition. That was 13 years ago, and the issue remains unresolved.

As I have indicated, NHTSA has worked with the industry and the Society of Automotive Engineers to develop J1802 to rate brake block effectiveness. Unfortunately, the procedure does not give repeatable results, and so is not reliable in its determinations. The agency has not committed recent funds to find out why this is the case or to perfect the test.

During the last 30 years, NHTSA has made many rules, and conducted many tests related to truck tractor brakes. ABS, for example, has been tested and mandated, and plays a valuable role by providing greater steering control when the road surface is slippery. Though this technology comes into real-world play infrequently, NHTSA invested millions of dollars and countless man-hours in its development.

On the other hand, brake balance—which requires appropriate brake lining effectiveness—is a factor in every single stop a truck makes. Brake balance, having every brake do its fair share of the work, is a factor in not only every stop but also when the vehicle is being slowed or retarded on grades. Replacing worn brake lining with that having incorrect effectiveness upsets brake balance. Yet a brake lining effectiveness rating, to help ensure that brake balance is maintained when brakes are repaired, is absent in the Federal Motor Vehicle Safety Standards even though it plays an important role each time the brakes are used.

If past is prologue, the trucking industry is likely to wind up with the most advanced, electronically-controlled brakes, and we still won't be able to replace worn-out brake linings with any degree of certainty that the refurbished systems will function as they were intended. And in spite of their capabilities when new, improperly maintained brake systems will not improve safety.

Since NHTSA has not moved decisively on this important and very basic issue, ATA is asking Congress to exercise its oversight authority and designate funds for the necessary research and rulemaking in the NHTSA budget process.

Brake lining effectiveness ratings may not sound as exciting as electronic braking, radar warning or other complex new subsystems that have a cheering constituency. They play a central role in the safe operation of a well-maintained vehicle, however, and that should matter more.

After 30 years of waiting for help from NHTSA, the consumer still can not replace worn brake linings and be certain that the repaired brakes retain the capability that the agency has mandated in FMVSS 105 and 121 as vital for the safety of new vehicles.

In desperation consumers have tried to resolve this on their own. The Maintenance Council of the ATA has created a stop-gap measure providing some information on one size of replacement brake lining. TMC RP 628A "Aftermarket Brake Lining Classification" aids in purchasing replacement brake lining by outlining the 40-psi torque value for certain linings as tested in compliance with FMVSS 121. These ratings are listed in a publication overseen by the SAE Brake Lining Performance Review Committee and published by The Maintenance Council. Not only are linings listed, using funding provided by TMC certain of the products are checked each year to see if they perform as indicated. And since March 1995 when the RP was first issued, products of at least three manufacturers have been found to be substandard.

TMC RP 628A does not, however, help consumers determine the effectiveness rating of the worn lining they are removing. Neither does it give the effectiveness of any new lining, even those it lists. It is also of no help with the many truck air and hydraulic brakes that are of a size other than 16.5x7. And it is a voluntary program, with many suppliers choosing not to take part. So it is seen as a stop-gap measure that affords a modicum of help until a standardized effectiveness rating is established and all linings are marked.

In conclusion, I'll note that NHTSA has, through FMVSS 105 and 121, done much to increase the complexity of new truck brakes to improve safety. System redundancy and performance are mandated fostering fail-safe, short, controlled-panic stops. Also the Federal Motor Carrier Safety Administration has regulations (FMCSR 393 Subpart C) and roadside inspections to ensure that motor carriers keep these brakes repaired. But neither agency has yet provided the assistance the consumer most needs to properly replace worn brake linings. Until NHTSA mandates that brake linings be graded and permanently marked with a standardized effectiveness rating there is no way to ensure that the consumer can replace them with the proper material.

Additional reference:

For additional discussion and background, see:

"The Effect of Aftermarket Linings on Braking Efficiency," M. A. Flick, R. W. Radlinski, and R. L. Kirkbride, Society of Automotive Engineers, Paper no. 870267 (1987).

APPENDIX B

Presentations from the TMC Brake Linings Forum

(Charlotte, NC, October 17, 2002)

Copies of the visuals in this appendix are shown in the order of their original presentation and without editing or other modification. They represent the viewpoints of the presenters at that time, and not necessarily those of Oak Ridge National Laboratory or the Department of Transportation. Visuals have been reproduced from the best available copy, however, the authors' selection of colors and the use of standard TMC templates has reduced clarity of reproduction in certain cases.

Presentation title, author, link

<i>Current Aftermarket Rating Systems - Recommended Practice RP 628</i>	<i>pdf</i>
James R. Clark , Chief Engineer, Foundation Brakes and Wheel Equipment, Dana Corporation, Spicer Heavy Axle and Brake Division	
<i>Current Dynamometer-Based Brake Rating Methods</i>	<i>pdf</i>
Charles W. Greening, Jr. , President, Greening Test Labs	
<i>Lessons Learned from the Brake Manufacture Council's 'Passenger Car and Light Truck Voluntary Friction Certification Program'</i>	<i>pdf</i>
Tim Duncan , General Manager, Link Testing Services	
<i>A Fleet Operator's Perspective on Brake Lining Selection</i>	<i>pdf</i>
Dennis J. McNichol , President, Dennis National Lease	
<i>A Perspective on the Shortfalls of Lining Ratings</i>	<i>pdf</i>
Jim Fajerski , Business Manager, OE Sales and Applications Engineering, Federal Mogul Corporation	
<i>Challenges for the Development of a Practical Friction Material Rating System</i>	<i>pdf</i>
Peter J. Blau , Metals and Ceramics Division, Oak Ridge National Laboratory	

APPENDIX C

Truck Brake Lining Rating Methods

A report prepared by

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*Work performed under ORNL Subcontract no.: 4000023475

Background

The major concern of the truck fleet operators when replacing brake lining materials is that the vehicles can be controlled and stopped in a predictable, consistent, and safe manner. The vehicle should have the same feel and behavior to the driver after relining as it did with the original lining material before the brakes were relined. Ideally the friction material should be replaced with original equipment linings of “like-with-like.” Since American truck operators select friction materials from a large number of suppliers, “like-with-like” replacement generally does not take place. This makes it difficult to balance brake performance between the wheels, and between tractor and trailer, and maintain familiarity between vehicles within the fleet. The consequences are unpredictable braking and vehicle behavior that often cause serious accidents. The reason for not being able to replace “like-with-like” is the significant variation in performance of materials rated similar or equivalent by the current evaluation and rating method (TMC RP 628 derived from FMVSS 121 tests). This is of great concern to the fleet operators.

Another fleet operator concern when selecting replacement friction materials, after the performance criteria are satisfied, is wear life versus cost. Currently no data is available on wear from TMC RP 628.

C1. Materials Evaluation and Rating Issues

C1.1 Test Equipment and Hardware

The currently used method to evaluate and rate friction materials is the TMC RP 628 that uses a limited set of data from FMVSS 121. FMVSS 121 is required for original equipment, but aftermarket trucks do not have to pass this test even though they outnumber new trucks on the roads many times over. Even though this test uses a fixed drum brake size, 16.5” x 7”, many other variables are involved, such as:

- Brake design
 - actuation mechanism and its efficiency
 - dimensions and geometry
 - materials of components
 - thermal characteristics
 - cooling efficiency
 - lining/drum conformity
- Air chamber
 - size
 - spring strength

- Slack adjuster design and efficiency
- Dynamometer characteristics
 - mechanical capabilities
 - cooling
 - inherent energy losses
 - thermal mass
 - operating procedure
 - test fixture set-up

These factors contribute to the variability in performance of the friction materials even though they are given the same torque rating in RP 628. Some of the factors contributing to this variability would be reduced if the testing were done by the same institution on the same equipment following a rigidly controlled procedure. The test laboratory should be completely independent of the OEMs, brake suppliers and friction materials producers.

C1.2 Test Conditions

The tribological performance of the materials of the friction couple is affected by the unit contact pressure (contact stress) between lining and drum, sliding velocity, and temperature as well as its thermomechanical history. Since FMVSS 121 incorporates the variable and non-quantifiable factors listed above, the “true” interface conditions determining the tribological performance of the materials are not known and can be very different from case to case even though the test air pressure is the same. The outcome is that materials with different friction characteristics would be included in the same torque rating, and their “true” friction characteristics are not known. When a replacement lining is selected based on this kind of systemic data variability and uncertainty one can expect inconsistent and unpredictable brake performance. Research supported by NHTSA has shown that even if the same brake, set-up, conditioning, and test procedure was followed, the variability in measured performance was substantial when running FMVSS 121 dynamometer tests [1]. This suggests that to generate a meaningful friction materials performance database based on FMVSS 121/RP 628 alone is not likely to succeed in narrowing the variability of materials rated “identical.”

C1.3 Brake Operating Conditions

Another concern is the fact that the tribological performance (friction and wear) of currently used phenolic-binder friction materials is influenced by the operating mode of the vehicles. Here the temperature of the friction couple is the major factor determining the friction and wear performance. Tests have shown that the friction and wear can be the same even though the severity of the braking action is very different provided the temperature of the friction couple is the same [2, 3]. However, in practice the temperature increases with increasing brake severity and duration, but it may be different for the same brake if the heat transfer and cooling efficiency are different. Hence, the brakes of stop-and-go garbage trucks, for example, require different friction materials than those for long-haul on-highway trucks. In spite of this situation, FMVSS 121/RP 628, a test that is a “made-up” or fictitious brake application sequence, is used to determine and select friction material that matches the original lining performance for a specific brake design and/or vocation. Considering this situation FMVSS 121/RP 628, as it is used today, may not be the best method to evaluate and rate friction materials for brakes. Furthermore, even the well-controlled NHTSA round-robin study mentioned above resulted in significant differences in the performance for supposedly “identical” test hardware, conditioning and test procedure [1].

C1.4 Wear

Wear is not included in FMVSS 121/RP 628 even though it is an important consideration for selecting friction materials from an economic as well as a public safety consideration. The total amount of friction materials used in the United States for on-road vehicles is in the order of 1.38×10^8 pounds per year [4]. Most of this material is turned into dust that is expelled into the environment with the potential to cause environmental and health problems. The concentration of this debris in the environment is most acute in the cities because of the confined space and limited opportunity for dispersion. Furthermore the operating mode of city buses results in wear rates of the brake linings that are 30 to 50 times higher than what is typical for long-haul on-highway trucks. Consequently, in addition to an economic benefit from friction materials with good wear resistance there is also a public health benefit. Hence, a database for brake linings should also include data on wear rate.

C2. Proposed Evaluation Method

We propose that FMVSS 121 be supplemented with a well-controlled sub-scale tribology test that provides friction and wear data under known conditions. Since it is not feasible to test all materials for all possible operating modes, a few typical operating modes may cover most of the vocations. Say, stop-and-go operation typical of city buses and garbage trucks, long-haul on-highway vehicles, and trucks operating in mountainous terrain. Each of these has a unique brake application profile that can be recorded during typical truck runs in terms of speed (drum/lining relative velocity), brake pressure (drum/lining contact stress) and lining temperature. These are the primary determining parameters for the performance of the friction materials. Such information is already available at major brake manufacturers and possibly also at large fleet operators. From this data one can develop brake application spectra typical of the vocations. The tribology test to evaluate and rate friction materials should then be run according to these spectra and reported for each vocation category on the same materials as tested according to FMVSS 121 for original equipment. It will provide more comprehensive friction and wear data under known conditions than is obtained from FMVSS 121. It will also show how different vocations influence the tribological performance of the materials. "New" or modified materials for the after-market not tested as original equipment should be tested according to the tribology test procedure. The data on these "new" materials can then be compared one-on-one with the data for the original materials tested the same way but also by FMVSS 121. This database will enable the truck operators to select friction materials to better match the original lining performance and fit their specific truck operating profiles than today's RP 628 database based on FMVSS 121. This approach will reduce the variability and uncertainty associated with FMVSS 121 as well as providing data determined based on the operating mode of the trucks rather than a "made-up" or fictitious brake application scenario.

Spectral loading was adopted for fatigue testing many years ago when it was found that simple constant amplitude and frequency were not representative of most applications. That situation was similar to where brake testing is today where the performance of the materials are ranked using one "made-up" test (FMVSS 121/RP 628) for all vocations.

Current dynamometers could be programmed to run spectral tests. However, since the dynamometers may have different characteristics (thermal mass, heat transfer, and cooling, etc.) it may not be possible to ensure that the conditions (temperature and contact stress in particular) at the lining/drum interface are the same from test system to test system. Since the key parameters-- temperature, sliding velocity, and contact stress -- are known from the spectral brake profiles, corresponding to specific vocations, the tribological performance of the friction materials can be measured using a computer controlled sub-scale tester. This approach will substantially reduce the time and cost of evaluating and rating friction materials while providing tribological data under known conditions and thereby reduce the variability in performance

experienced with the currently used brake lining testing/rating system. Another benefit of this approach is that it is applicable to both drum and disc brakes.

C2.1 Sub-Scale Testers

Two sub-scale testers, the FAST and the Chase testers, are extensively used to primarily develop new friction materials. These machines generally have inadequate temperature control and with some exceptions also lack computer controls enabling spectral “braking.” A sub-scale tester capable of testing at predetermined temperatures and spectral “brake” application has indicated that testers with the capabilities required to generate the needed tribological data outlined above is feasible [5, 6]. It is possible that existing FAST and Chase machines could be modified to incorporate the features required to replicate various brake spectra.

C3. Proposed Action Plan

C3.1 Short Term

1. Determine, in cooperation with the truck operators, what would be meaningful vocations to use to establish relevant brake application spectra.
2. Gather brake application data from truck runs for the selected vocations.
3. Formulate test specifications including test spectra.
4. Develop design criteria for a sub-scale tester that can run brake spectra under controlled conditions.
5. Evaluate capabilities of currently available sub-scale testers, and determine if they can be modified to run spectral testing at required test conditions.

C3.2 Long Term

1. Design and fabricate a prototype tester.
2. Demonstrate that the tester can run tests according to test specifications (spectra).
3. Run spectrum tests on friction material that has passed FMVSS 121 as well as other friction materials rated identical according to RP 628.
4. Choose a truck with original brake linings for a specific vocation and track lining performance.
5. Use the existing RP 628 database to select a replacement for the original friction material, install on the selected truck (4), and track the lining performance.
6. Select friction material from the sub-scale database for the same vocation as above (4), install it on the truck and track the lining performance.
7. Compare the results from 5 and 6 with those from 4.

C4. References

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4. Y. Naerheim, Market research to determine: (1) the annual consumption of drum/rotor and lining/pad materials in the United States and world, and (2) the energy required to produce the materials.

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APPENDIX D
List of Selected Brake Lining Testing Practices

Designation	Title / Subject	Description
FAST Test	<i>Friction Assessment and Screening Test</i>	Uses 1"-square pads with a spinning disc. 90 min., continual drag test adjusts normal force to maintain torque. Measures wear by weight change.
FMVSS 121 (see details following this table)	<i>Air Brake Systems</i>	Involves both a vehicle portion with a table minimum stopping distance requirements and a dynamometer portion involving 438 stops to conduct burnishes, measure effectiveness, brake power, and fade recovery.
TMC RP 628	<i>Aftermarket Brake Lining Qualification</i>	Publishes braking torque values, obtained at a pressure of 40 psi, which are obtained from the dynamometer portion of FMVSS 121. (see the FMVSS 121 summary)
SAE J 379	<i>Gogan Hardness of Brake Lining</i>	A measure of lining compressibility indicated by the distance of penetration of an indenter (in units of 0.0064 mm) into the surface of a lining after the application of a minor load that is increased up to a set major load.
SAE J 661	<i>Brake Lining Quality Test Procedure</i>	Uses a friction materials test machine (Chase machine) to perform a series of applications to establish a baseline, measure fade, fade recovery, and wear (weight loss and dimensional change). 152 brake applications comprise a test.
SAE J 866	<i>Friction Coefficient Identification System for Brake Linings</i>	Method for marking friction coefficients (ranges) on brake linings; includes notice that it will be deleted when satisfactory methods for determining friction are instituted in J 1802 (drum brakes) and J 2430 (disc brakes).
SAE J 1802	<i>Brake Block Effectiveness Rating</i>	Dynamometer-based procedure involving a series of burnishes and drags to determine normal and high-temperature brake effectiveness. At least 409 stops are required, depending on the sequence followed and the number of drum heat-up applications.
SAE J 1854	<i>Brake Force Distribution Performance Guide</i>	Establishes target threshold pressures for gladhand air pressure lines.

SUMMARY OF THE FMVSS 121 (DYNAMOMETER PORTION)

(This abbreviated summary is not intended to be a working substitute for the actual test procedure. Section numbers in brackets refer to those in the original document.)

Terminology:

Average deceleration rate = the change in velocity per unit time ($\Delta v / \Delta t$), starting from the beginning of deceleration [§5.4][change in velocity or time is usually measured as “delta,” not that diamond sign]

Brake retardation force = (sum of brake forces / sum of GAWRs relative to chamber pressure) and corresponds to Column 1 of Table II in the regulation [§5.4.1]

IBT = initial drum temperature at the start of braking

A. Burnish [ref. §S6.2.6]: (total number of applications = 400)

- Make 200 stops from 40 mph at 10 ft/s² with 315° F 5 IBT 5,385° F
- Make 200 stops from 40 mph at 10 ft/s² with 450° F 5 IBT 5,500° F

(To increase IBT to the desired initial temperature, conduct stops from 40 mph at 10 ft/s². To decrease the IBT rotate the drum or disc at 30 mph).

B. Brake Retardation Force. [§ 5.4.1.1] (total applications = 7)

With 125° F 5 IBT 5,200° F, and beginning with 20 psi chamber pressure:

- Decelerate from 50 to 15 mph at 9 ft/s². Record average torque.
- Increase chamber pressure by 10 psi, rotate the drum or disc until the temperature drops into the specified range and repeat (six times).

Total of seven decelerations at 20, 30, **40**, 50, 60, 70, 80 psi.

NOTE: *The 40 psi value in the above sequence is currently used for TMC RP 628.*

C. Brake Power. [§ 5.4.2] (total applications = 11)

Begin with 125° F 5 IBT 5,200° F for the first application.

- Conduct 10 decelerations from 50 to 15 mph at 9 ft/s² at equal intervals of 72 s counting from the start of deceleration of the previous application. (Line pressure not to exceed 100 psi for any application)
 - After last deceleration and running at 20 mph, decelerate to stop at 14 ft/s²
-

D. Brake Recovery. [§ 5.4.3] (total applications = 20)

Begin 2 minutes after completing 5.4.2.

- Make 20 stops from 30 mps at 12 ft/s^2 with (20 psi ♦ line air pressure ♦ 85 psi) for non-antilock system or (12 psi ♦ line pressure) for an anti-lock system.

TOTAL NUMBER OF BRAKE APPLICATIONS = 438, including the burnishing stops

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